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ENVIRONMENTAL SCIENCES DIVISION

ANNUAL PROGRESS REPORT
PERIOD ENDING SEPTEMBER 30, 1972

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION FOR THE U.S. ATOMIC ENERGY COMMISSION

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.95

ORNL-4848
UC-48 — Biology and Medicine
Environmental Sciences Division Publication No. 480

Contract No. W-7405-eng-26

ENVIRONMENTAL SCIENCES DIVISION

ANNUAL PROGRESS REPORT

For Period Ending September 30, 1972

S. I. Auerbach, Director
D. J. Nelson, Assistant Director
E. G. Struxness, Assistant Director

FEBRUARY 1973

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Oak Ridge, Tennessee 37830
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UNION CARBIDE CORPORATION
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Contents

Preface

The past year was another one of dynamic change for the Division. Most noticeable is a name change – from Ecological Sciences to Environmental Sciences – which reflects the broadened missions and research programs of the Division. Under this new rubric, more emphasis is placed on strengthening the Earth Sciences and the radiological hazards analysis capabilities in the Laboratory, with particular emphasis on the environmental pathways associated with transport, accumulation, and dose to human populations. Edward G. Struxness, who had been Assistant Director of the Health Physics Division, joined the Division as Assistant Director with particular responsibilities for the radiological hazards analysis and assessment programs, and the applied programs related to radioactive waste management, while continuing his comprehensive Laboratory responsibilities as Director of the Environmental Impact Statement Project.

Organizational changes in the Division last year included the establishment of an Environmental Hazards Studies Project under Stephen V. Kaye, who has responsibility for the radiological hazards analysis and assessment programs, and the establishment of a new NSF-RANN program in Ecology and Analysis of Toxic Contamina. The Division's responsibilities in this program are encompassed by the Toxic Materials in the Environment Project under Robert I. Van Hook. The aquatic research was reorganized with B. Gordon Blaylock assuming responsibility for leadership of the new Applied Aquatic Studies which consolidated previously separate work on radionuclide cycling and radiation effects in aquatic systems as well as basic research in aquatic ecosystems. The large effort in modeling and related mathematics that pervades all programs of the Division is now coordinated by Robert V. O'Neill, and a Long Range Planning Committee was established with Jerry S. Olson serving as Chairman.

Changes in physical facilities accompanied the changes in organization. Building 3504, formerly used for radioactive waste management studies, was assigned to the Division for housing the radiological hazards analysis and earth sciences groups. A new aquatic research laboratory for thermal studies (Bldg 1504) was completed and put into operation.

Activities associated with analysis of environmental impacts of nuclear power plants and related facilities continued to challenge a large portion of the technical staff. To help meet this need as well as to augment the Division's programs in aquatic and earth sciences, 12 new scientists joined the Division. These were selected after the most intensive search and recruitment activities in the Division's history. Each brings a special ability in his area of expertise and offers great promise for strengthening our total research program.

While these major changes were taking place, the Division continued its long-term efforts in Ecosystem Analysis, including additional research in the Cesium Forest and Walker Branch Watershed, and augmented its already strong research and managerial participation in the International Biological Program.

It has been an exciting, demanding, and dynamic year for the Environmental Sciences Division. Our contributions as well as our potential for aiding the AEC in its missions have received increasing recognition. We look forward, therefore, to the next year with a heightened sense of both accomplishment and challenge.

1. Radionuclide Cycling in Terrestrial Environments

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Terrestrial environments may receive radioactivity from various sources of nuclear technology; that is, weapons testing, nuclear excavation, natural gas stimulation, fuel element processing, reactor power plants, and conceivably from transportation accidents. In national nuclear technology developments, a responsible environmental policy will require a comprehensive understanding of the behavior of radionuclides in ecological systems in order to assess the radiological effect on endemic organisms. An established and continuing objective of the Environmental Sciences Division is the study of the fate of fission products and other radionuclides in different ecosystems.

Research on radionuclide cycling is designed to determine the mobility of radionuclides in major segments of terrestrial environments. Reciprocal transfers of environmental radioactivity are investigated for three major components – soil, plant, and animal – of forested and grassland ecosystems. The principal research strategies are to determine the pathways and rates of radionuclide transfer among major components of both native and managed ecosystems. Concentration in biotic components, dispersion by natural biogeochemical cycles, and fixation by abiotic sinks are the processes affecting radionuclide behavior in ecosystems. Dynamic characteristics first are determined with manipulated microcosms, and then results are validated in large-scale field-plot and ecosystems experiments. Investigation of radionuclide behavior at the atmosphere-plant and soil-plant interfaces illustrates how hazardous materials initially enter biological circulation. Although a vast array of animal life interacts with plants and soil, causing movement of radioactivity in food chains, the concentration or dispersion of radioactivity through trophic exchanges is determined for specific animal pathways.

Research on radionuclide cycling is related to other AEC and federal programs. Data on ecological transfers aid the interpretation of environmental behavior of hazardous radionuclides (Impact Statement Assessments). Determination of mechanisms of radionuclide transfer embraces fundamental studies of biochemical cycles (IBP). Cycling research data have been applied in ecological assessments related to the Federal Radioactive Waste Repository Project. Investigation of radionuclide behavior often requires unusual experimental approaches. New techniques or unique applications of existing technology are frequent and important spin-off results from radionuclide cycling investigations. Devel-

1. Dual capacity.
2. IAEA International Fellow, University of Ife, Ile-Ife, Nigeria.
3. Great Lakes Colleges Association Participant, Kenyon College.
4. IBP research assistant, UT graduate program in ecology.
5. Temporary employee.
6. NSF undergraduate research participant.
7. Consultant.
8. ORAU University Participant, University of Wyoming.
9. ORAU undergraduate research participant, Emory University.
10. Alien guest, Volcani Institute for Agricultural Research, Dayan, Israel.

opment of new methodologies enhances the solution of problems on radionuclide technology and aids the general investigative efforts in the scientific community.

SOIL CHEMISTRY

Soil chemistry mechanisms partially control the biotic availability of radionuclides over long time periods. Chronic burdens in plants and animals are affected by chemical fixation-release reactions involving soil minerals and solutions. Sediments from White Oak Lake (WOL) have accumulated reaction products of many radionuclides since 1943, from disposal of low-level radionuclide wastes. The chemical form of radionuclides was determined for soils from exposed upper WOL alluvium. The objective was to determine the character of secondary reaction products and nuclide availability to plants after weathering under natural environments.

Nine extractants (1 N NH_4OAc, pH 7; 1 N OAc, pH 4; 1 N H_2SO_4; Bray 1; Bray 2; 1 N KCl; 1 N $MgCl_2$; 5% EDTA; and 5% DTPA) were tested to determine the efficiency of ^{60}Co, ^{125}Sb, ^{137}Cs, ^{106}Ru, and ^{65}Zn removal from WOL soil. Acid extractants were more effective in removing ^{60}Co than neutral extractants. One-normal sulfuric acid at a soil-to-solution ratio 1:25 extracted the greatest quantity of ^{60}Co, but 1 N NH_4OAc (pH 4) and the Bray 2 (an extractant used extensively to determine available soil phosphorus in neutral to calcareous soils) extracted equivalent amounts at a soil-to-solution ratio 1:120 at 24 and 72 hr. The chelating agent EDTA was the most effective extractant for ^{60}Co at soil-to-solution ratio 1:120, a fact which may indicate that a considerable fraction of cobalt is associated with the organic component of the soil. Selective removal of amorphous iron, however, revealed a larger portion of the cobalt to be adsorbed or occluded in these compounds than that held by the soil organic matter. Strong acid extraction (H_2SO_4) was ineffective in the removal of ^{137}Cs; the most effective extractants were KCl and NH_4OAc pH 7, indicating the cesium to be strongly adsorbed to nonexpandable 2:1 layer silicates.

Extraction studies as well as distribution analysis between particle size fractions revealed that more than 50% of the ^{106}Ru and ^{125}Sb was present in the soil organic matter complex. The ^{106}Ru associated with the mineral fraction appears to be of the form $R_2O_3 \cdot nH_2O$. Antimony-125 on the mineral component is probably adsorbed to the iron and aluminum oxide coatings in the form of a complex anion, since the Bray extractants were more effective than all other extractants. The fraction of WOL soil radioactivity associated with organic matter (^{60}Co, ^{106}Ru, ^{125}Sb, ^{65}Zn) will likely be recycled through biological pathways and thus be more available for plant uptake than those irreversibly adsorbed on micaceous silicates (^{137}Cs), and those within amorphous iron-aluminum clay coatings (^{60}Co, ^{106}Ru, ^{125}Sb).

ROOT-SOIL RELATIONS

Root uptake from the available soil pool accounts for the long-term radionuclide burdens in plants. Direct transfer from roots to soil is a common pathway of radionuclide movement in terrestrial ecosystems. Experimental results were obtained on plant uptake of ^{137}Cs, ^{106}Ru, ^{125}Sb, ^{60}Co, and ^{65}Zn from WOL-bed soils. Cesium-134 transfer from *Liriodendron tulipifera* roots to soil was determined in a further refinement of the root-to-soil radionuclide cycling pathway.

The influence of N, P, and K fertilization on crop uptake of radionuclide (^{137}Cs, ^{106}Ru, ^{125}Sb, ^{60}Co, and ^{65}Zn) was determined for WOL soil. For soil concentrations ranging from 0.15 pCi/g (^{65}Zn) to 3.4 μCi/g (^{137}Cs) and 17 pCi/g (^{60}Co), only ^{137}Cs and ^{60}Co could be detected in shoots of Japanese millet after five harvests. Potassium fertilization reduced ^{137}Cs uptake. Medium level of nitrogen fertilizer increased, but high nitrogen (100 ppm) suppressed ^{137}Cs uptake. The effect of nitrogen and potassium fertilizer was similar for ^{137}Cs concentration in both seed and stalk parts of the plant. Cobalt-60 concentrations in millet were increased by nitrogen-fertilizer applications, unaffected by potassium, and increased slightly by phosphorus amendments.

Continuous cropping of millet on WOL soils resulted in a fifth-harvest concentration factor of 0.017 for ^{60}Co, a slight increase from the initial harvest value, 0.013. Conversely, the concentration factor for ^{137}Cs decreased from 0.032 to 0.026 for successive harvests. The value for ^{137}Cs was similar to that reported by Menzel,[11] but our value for ^{60}Co was several orders of magnitude lower than literature values (0.01 to 0.02 vs 0.1 to 10), which were based on water-soluble forms applied to the soil six months prior to uptake experiments. Comparison of these sets of data indicates that long-term soil-radionuclide reaction influences the availability of ^{60}Co to plants. Cobalt seems to be removed from biotic circulation following a period (ca. 25 years) of reaction and removal by soil minerals.

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11. R. G. Menzel, *Health Phys.* 11, 1325–32 (1965).

Soil organic separations made by density gradient centrifugation of >50-μ-diam particulates revealed high concentrations of ^{60}Co, ^{106}Ru, and ^{125}Sb in the organic fraction of WOL soil. The organic material was largely root debris. High activity of radionuclides in this fraction was surprising since plant uptake studies revealed concentrations in the foliar portions were 100-fold lower. Roots evidently have the ability to extract these radionuclides from the soil complex, but translocation to the foliar portion is quite small. Thus movement of radionuclides to and into the roots appears to be a significant process in the recycling of radionuclides even though they are not transferred to aerial portions of the plant. This type of recycling probably plays a greater role in subsequent radionuclide movement through soil profiles than transport by strict soil physical-chemical processes.

Two-year-old *Liriodendron tulipifera* saplings tagged with ^{134}Cs confirmed observation on the rapid intraplant transfer to roots, and the experiments refined the role of small roots in the root-to-soil transfer pathway. Within one week of the stem tag, over 25% of ^{134}Cs was in roots, and transfer to soil already had occurred. Small roots (<1 mm in diameter) contained over 40% of the nuclide in roots. This size class of roots was rapidly turning over, and it accounted for approximately 50% of the nuclide (and presumably other elements) movement to soil through root death. The remaining 50% transfer was from root leaching and exudation. Of the total annual ^{134}Cs transfer to soil, 33% was due to rainout and leaf drop, and 67% was by root processes. Rapid downward movement of shoot-assimilated radionuclides to roots tends to short-circuit the recognized pathways, rainout and litterfall. Direct transfer to roots, rapid root turnover, and fixation by soil comprise a significant pathway of transport to the soil sink, thereby removing the hazardous nuclide from biological circulation. This pathway would be important in forests where the foliage canopy effectively filters radioactivity, nutrient elements, and toxic elements from the atmosphere. Foliar assimilation and internal transport by the tree would bypass organic pools on the forest floor. The process represents a cycling pathway in which intraplant mass transport of elements may be equivalent to or greater than the litterfall-decomposition route.

RADIONUCLIDE CYCLING IN THE DETRITUS-SOIL-ROOT PATHWAY

Fluxes of radioactive, toxic nutrient elements in the environment are influenced significantly by biophysical processes at the litter-soil interface. Experimental microcosms were designed to determine the fluxes of radionuclides (toxic and nutrient elements) in simplified microcosm experimental designs. The behavior of CdO and Cd^{2+} was determined in both sterile and nonsterile soil systems. Leaching of sterile sand containing $^{109}Cd(NO_3)_2$ removed 60% of the cadmium in three weeks. By comparison, leaching removed only 0.1% of ^{109}Cd from a sterile silt loam. When these substrates were inoculated with a natural microflora, leaching removed 42 and 0.4% of ^{109}Cd in sand and soil respectively. Microbial action increased Cd^{2+} loss from soil and decreased Cd^{2+} loss from sand; that is, in sand, microbial immobilization apparently minimized Cd^{2+} leaching losses. The microflora in soil also immobilized Cd^{2+}, because 71% of total cadmium was located in the top 2 mm, compared with 40% in sterile soil. Cadmium immobilization in soil was apparently overshadowed by microbial maintenance of soil structure and possible formation of chelating or complexing loss of cadmium from nonsterile than from sterile soil. In contrast, neither maintenance of soil structure nor formation of chelating agents would greatly affect Cd^{2+} leaching from the porous sand with its low adsorptivity.

Prior studies[12] described microbial reduction of cadmium diffusion into sediment at the water-sediment interphase of aquatic systems. Continued studies confirmed the same effect for zinc. The sediment surface accumulated 76% of the cadmium and 89% of the zinc that had been added to the water in free ionic form. In natural mud sediment, microbial action intercepted and immobilized in the top 2 mm from 80 to 90% of the cadmium and zinc that otherwise would have diffused deeper into the sediment. Sterile sediments only accumulated 45 and 44% of the cadmium and zinc added to the water respectively. Microbial action at the water-sediment interphase may double removal of heavy elements from water. Microbial activity also reduces diffusion into the substrate by almost an order of magnitude by immobilizing these elements in the top 2 mm. Decomposers (bacteria, fungi, etc.) did not selectively accumulate cadmium in the sediment when the element was added in the insoluble CdO form. In contrast, uptake by algae and sterile detritus was two to three times greater when CdO was the source compared with uptake of Cd^{2+} by algae and detritus. Apparently the algae and detritus physically captured CdO to a larger extent than Cd^{2+}, perhaps by an adsorption process.

12. S. I. Auerbach et al., *Ecological Sciences Div. Annu. Progr. Rep. Sept. 30, 1971*, ORNL-4759, p. 26.

Rate of nitrogen and sulfur mineralization from decomposing tulip poplar (*Liriodendron tulipifera*) leaves was determined in an intact soil-core system. Sulfur-35 and nitrogen-15 labeled leaves were placed on soil core surfaces as simulated litterfall. Rate of nuclide loss from the litterfall source represents the mineralization rate. Two distinctly different trends were observed for sulfur and nitrogen; sulfur was released at a rate of 0.0005 day^{-1} in a linear pattern over a 100-day interval. The nitrogen release rate was greater and appeared to be nonlinear. At least two components characterize the loss rate; over the 0-to-100-day period the rate was roughly 0.0025 day^{-1}, a rate which was five times faster than sulfur mineralization. In the 100-to-300-day interval the rate roughly paralleled that for sulfur. Approximately 35% of the nitrogen was mineralized from the litterfall input after 275 days. A total of 10 to 15% of the initial ^{35}S in leaves was released after 275 days. After 25 weeks, most of the released sulfur remained in the organic detritus layer. Then approximately 25% moved to the mineral soil. In contrast, approximately 70% of the mineralized nitrogen remained in the surface organic layer and 30% was in mineral soil after *only* two weeks. Five weeks later, the distribution of mineralized nitrogen was reversed — 75 and 25% were in soil and litter respectively. Dissimilar mineralization rates for sulfur and nitrogen illustrate relative differences in mobility and cycling of these nutrient elements. Nitrogen is highly dynamic, whereas decomposer organisms immobilize and conserve sulfur at the litter-soil interface.

FOOD CHAIN DYNAMICS

Research on food chain transport of radioactivity by animals is designed to determine pathways of movement, rates of transfer, and magnitude of concentration or dispersion. While concentrations of radionuclides often may be negligible, high feeding and elimination rates would enhance the cycling of radioactivity in terrestrial environments.

Whole-body concentrations and turnover rates of radionuclides are often treated as constant and independent parameters in food chain studies. Turnover rates of elements are influenced by feeding rates, assimilation efficiencies for specific elements, and excretion rates. Changes in turnover rates also affect the radionuclide concentration at equilibrium, the latter being a function of the concentration in the food base and the turnover rate. Interdependence of equilibrium concentration and turnover rate was demonstrated experimentally using a millipede which practices refection (reingesting material previously defecated). Fed a ^{137}Cs-tagged food source, the control group (Fig. 1.1, solid line) attained 95% of equilibrium body burden within 62 days, with an uptake of 0.0484 day^{-1}. Organisms denied refection (broken line) doubled their ingestion rate (of leaf litter), which resulted in a doubling of the uptake rate (to 0.0997 day^{-1}) and halving of the time to equilibrium. The resultant equilibrium body burden was 71% of that of the leaf litter plus feces. Although radionuclide concentration was reduced by some 50% on initial passage, ^{137}Cs was more readily available on subsequent reingestion. Thus increases in assimilation rates can compensate for reductions in food concentrations. Variation in assimilation efficiency is an important factor which affects body burdens, and the variability of this parameter needs to be explored for a range of food resources with different animals.

Cadmium is a toxic element always found in association with zinc in the earth's crust. It is released as an atmospheric pollutant in association with zinc from zinc smelting and electrolytic refining operations, as well as from fossil fuel power production facilities. Material from these sources is transported to foliar surfaces or the soil. The sulfide and oxide forms are relatively insoluble; however, mildly acidic conditions

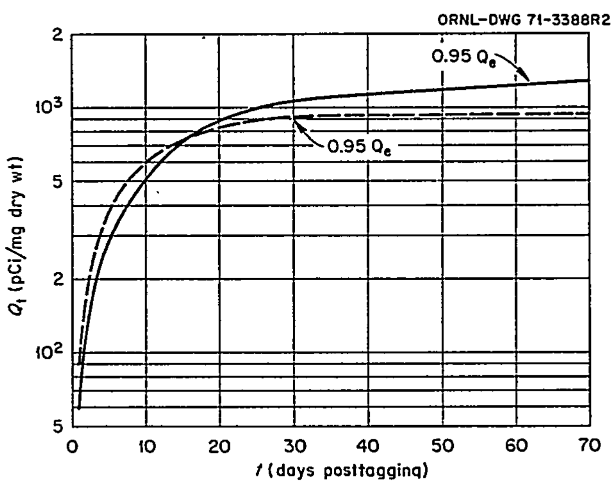

Fig. 1.1. Cesium-137 uptake by millipedes practicing refection (solid line) and those forced to alter their behavior and feed on primary foods only (broken line).

may solubilize these materials and render them available to be accumulated by animal systems. Transport and accumulation of cadmium through an old field food chain was examined.

Cadmium turnover in an arthropod community was determined with the aid of tracer techniques. Cadmium oxide behaved identically to cadmium nitrate through an invertebrate food chain. The nitrate form was therefore used in field experiments to ensure adequate transport of material through the system, since the oxide form might not move into the foliage rapidly enough due to insolubility. Cadmium nitrate was applied in a simulated rainfall to a fescue-broomsedge community and allowed to equilibrate for two and one-half months before introducing invertebrate omnivores (crickets) and predators (spiders). The resulting soil concentration of ^{109}Cd following two and one-half months was 18.8 dis min^{-1} mg^{-1} in the top centimeter. Cadmium-109 concentrations in the litter component of this community (Fig. 1.2) decreased through the month of August due to leaching, while concentration in foliage oscillated about a mean of 24 dis/min per milligram dry weight, indicating that some plant uptake had occurred by this time. The omnivorous cricket (*Pteronemobius*) feeding upon both litter and living vegetation reached an equilibrium concentration of cadmium of 185 dis min^{-1} mg^{-1} after ten days of feeding and remained stable at this level for the remainder of the animal's life span. Whole-body equilibration of ^{109}Cd by the predators (*Lycosa*) introduced with crickets was delayed 12 days when compared with that by the omnivore. This temporal delay was due to the fact that the crickets had to accumulate cadmium before it could be transferred to the spiders. Spiders reached an equilibrium of 130 dis min^{-1} mg^{-1} after about 25 days. Concentration ratios for ^{109}Cd, reflecting the amount of cadmium transported from one tropic level to the next, were: 1.2 for fescue/soil, 0.31 for crickets/fescue + litter, and 0.7 for spiders/crickets. These data indicate that although there is an accumulation of cadmium by various species, there was no food chain concentration.

Assimilation and biological turnover of ^{109}Cd was determined for the chipping sparrow, *Spizella passerina*. Chipping sparrows commonly are found in fields, parks, and sparse woodlands throughout most of North America in the spring and summer. It is a close associate of man, and its population increases in size as forest land is converted to agriculture and open space. The birds feed on the ground, where they find seeds and small insects, and glean insects from the foliage of trees. Uptake and elimination time of cadmium in the

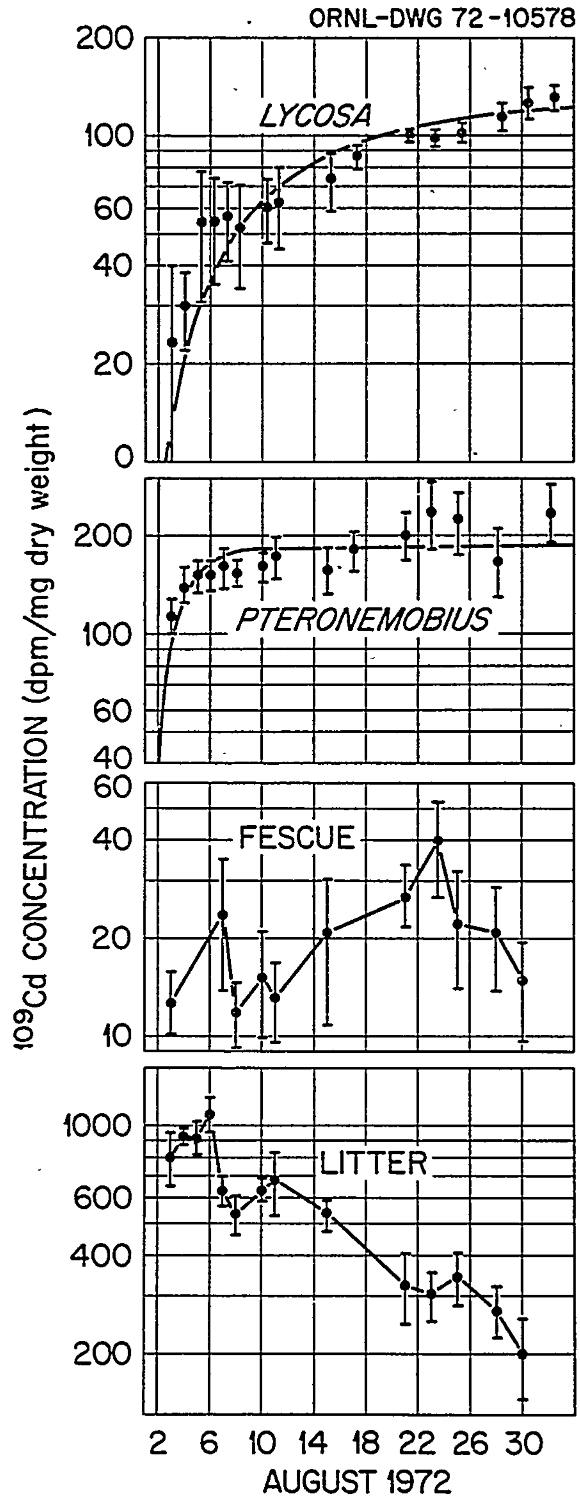

Fig. 1.2. Distribution of ^{109}Cd in the vegetative and animal components of a grassland community tagged in early May with a simulated rainfall contaminated with ^{109}Cd.

chipping sparrow was determined by feeding 14 birds, *ad libitum* (3.5 g/day), with ^{109}Cd-tagged wild bird seed (37.1 × 10^4 dis min^{-1} g^{-1}). Assimilation data were fitted with a one-component nonlinear uptake model, and elimination data were fitted to a two-component model. The birds reached an equilibrium body burden of approximately 3.0 × 10^4 dis min^{-1} g^{-1} after 17 days. After 22 days on tagged food, six birds were sacrificed, and brain, liver, heart, intestine, kidneys, muscles, and feathers were radioassayed. Significant ^{109}Cd was present in feathers (1.67 × 10^4 dis min^{-1} g^{-1}), liver (3.16 × 10^4 dis min^{-1} g^{-1}), kidneys (6.43 × 10^4 dis min^{-1} g^{-1}), and intestine (16.6 × 10^4 dis min^{-1} g^{-1}). The remaining eight birds were fed nontagged wild bird seed for 41 days. Radiocadmium in the birds' droppings decreased to zero after 36 hr. Whole-body counts decreased to 1.98 × 10^4 dis min^{-1} g^{-1} after 72 hr and did not change significantly during the remainder of the study. Initial elimination data indicated that 34% of the ^{109}Cd was found in the intestine and 66% in the body tissues. Appreciable retention of cadmium by sparrows illustrates the dynamic character of a toxic element in food chain mechanisms. Animals higher in the food chain (avian predators) conceivably could ingest threshold dosages of an element which is toxic at very low concentrations.

ECOSYSTEM DYNAMICS

Progress on modeling the behavior and fate of ^{137}Cs in ecosystems included analysis of the standing crop of the *Liriodendron* forest and its partitioning among structural components of the ecosystem. Regression analyses of data obtained since 1963 enabled estimates to be made of net annual organic matter accumulation in bole, branch, stump, and root components of the major species and established the trend for soil organic detritus accumulation. Evaluation of these parameters is a prerequisite for the forest ^{137}Cs model, since organic matter fluxes are the main transport mechanisms for cesium, and biomass represents an important sink for cesium in the ecosystem. These data are summarized in Table 1.1.

Liriodendron tulipifera comprises 78% of the above-ground biomass; total above-ground autotrophic biomass was 13.3 kg/m^2 and included annual leaf production of 374 g/m^2 and a pool of 625 g/m^2 of standing dead bole and branch material. The mean annual lateral root biomass was 1.68 kg/m^2, with 30% of this mass located in the upper 10 cm. Lateral root plus stump biomass was 3.74 kg/m^2, providing a root:shoot biomass ratio of 0.28 and a total living biomass for the ecosystem of 17.1 kg/m^2. Litter standing crop averaged 560 g/m^2, which, combined with soil organic detritus of 21.2 kg/m^2, yields a value for nonliving organic matter of nearly 22 kg/m^2, or nearly 1.3 times the total living biomass of the ecosystem.

SCIENTIFIC APPLICATION

Development of new techniques and unique application of concepts are frequent and important spin-off results from radionuclide cycling research. Evolvement of new methodologies enhances the solution of problems on radionuclides in the environment, and the results aid the general investigative efforts in the scientific community.

Table 1.1. Distribution of organic matter and annual biomass increments of vegetational components of the *Liriodendron* forest ecosystem. Sources of data and methods for determination are given in Reichle et al., *Carbon and the Biosphere Symposium*, AEC-CONF-720510 (in press), 1972.

Forest component	1970 Standing crop (g/m^2)				Total	Annual net accumulation (g/m^2)			
	Bole	Branch	Stump[a]	Foliage		Bole	Branch	Stump	Total
Liriodendron tulipifera	7,694	2174	1538	247	11,653	238	60	48	346
Other overstory trees	1,746	537	349	76	2,708	−14	−6	−4	−24
Understory trees	589	213	175	51	1,028	6	2	2	10
Herbaceous cover					28				0
Standing deadwood					625				0
Roots (lateral)					1,680				100[b]
Total	10,029	2924	2062	374	17,722	230	56	46	432

[a]Stump includes central tap and large lateral roots within a ~0.6-m radius.
[b]Net accumulation determined by difference in standing crops.

PVP[13] in Cation Saturation

Application of techniques developed in the soil zonal centrifugation program has provided improved understanding of the influence of saturating cations, for example, Na^+, Ca^{2+}, on physical-chemical properties of clay aggregation. In conventional x-ray diffraction techniques, it is quite difficult, and often impossible, to differentiate between sodium- and calcium-saturated montmorillonite. By using clay suspensions in 1% PVP, the cation – sodium or calcium – occupying the interlayers is easily distinguished by x-ray diffraction. At as much as 20% sodium saturation, the sodium ions occupy only external surfaces of montmorillonite, but at sodium saturations greater than 20% the sodium ions occupy both external and internal surfaces. On increasing sodium saturation, the montmorillonite crystallite, found to contain nine unit layers, breaks down to a dispersed condition containing sodium-saturated crystallites of only two unit layers. By using PVP-clay suspensions, it was possible to determine the location of the sodium ions on the montmorillonite surface, the size of the calcium-saturated clay particle, and its subsequent breakdown on increasing amounts of sodium. These attributes influence the specific physiochemical properties of montmorillonite and the general soil chemical characteristics of arid soils. By understanding the basic effects of sodium chemistry on clay aggregation, management techniques can be developed for making arid-zone soils more productive.

Plutonium Analysis of Environmental Samples

Knowledge of plutonium behavior in environments of southeastern United States is needed because nuclear sites using plutonium will be located at Oak Ridge (LMFBR) and Savannah River (Barnwell Waste Processing). Information on immediate and long-term environmental behavior of plutonium is essential to assure safety to man and endemic organisms, even for remote circumstances of plutonium release. Reliable and rapid analysis of plutonium in environmental samples is an essential requirement for both monitoring and research. Soil is the most difficult sample to analyze for plutonium because leach solutions contain very small amounts of plutonium accompanied by large quantities of interfering ions. In collaboration with the Chemical Technology Division,[14] a more useful procedure was developed in which plutonium was quantitatively separated from interfering contaminants, and the plutonium was determined with high efficiency using liquid scintillation techniques. At least 90% plutonium recovery and 100% counting efficiency (resolution ca. 0.3 MeV) have been attained with the new method.

A solution containing Pu(IV) and other metal ions in 1 to 4 *M* HNO_3, 3 to 4 *M* total nitrate, is mixed with tri-*n*-octylamine nitrate (0.3 *M*) in toluene. The plutonium and small amounts of iron are chelated by the amine. The aqueous phase is discarded and the organic phase washed with 3 *M* HNO_3 to remove the iron. Plutonium is stripped into a perchloric acid aqueous phase with the aid of an organic phase reductant. Most of the perchloric acid is removed by heating, and water is added. The plutonium [now as Pu(VI)] is extracted from this dilute perchloric acid solution into a combined scintillator-extractant solution. The time required for separation and radioanalysis is less than half that for conventional ion exchange and surface barrier detection. Test results for different methods and for other environmental samples are being compared in the refinement of this new technique for rapid analysis of plutonium in heterogeneous material.

Comparison of Microbial Parameters That Influence Nuclide Transfer

That microbes play an important role in the transfer of radionuclides is demonstrated in our model experiments with heavy-metal poisons and nutrient elements. Activity and volume of the microflora, in particular the fungi, are closely related to transfer and accumulation of mineral elements.[15] It is of fundamental importance to have reliable estimates of microbial activity and mass. The most reliable parameters are rates of gas transfer (O_2 consumption, CO_2 uptake) and direct or indirect counts of the microflora. A new criterion for microbial activity and possible mass is the content of adenosine triphosphate (ATP) in the microflora. Relationships between rates of CO_2 evolution, O_2 uptake, ATP content, direct microscopic measurements of microbial mass, weight of microbial mass, and indirect population estimates from viable spore counts were established in a model experiment. The dynamics of these parameters were followed in a model sand culture

13. PVP is polyvinylpyrrolidone, a recently discovered agent for suspending clays in nonaqueous density gradients. C. W. Francis, *Soil Science* (in press).

14. D. T. Farrar, W. J. McDowell, and M. R. Billings, *Plutonium Analysis in Environmental Samples: A Combined Solvent Extractive–Liquid Scintillation Method* (to be published).

15. M. Witkamp, *Soil. Biol. Biochem.* 1, 167–84 (1969).

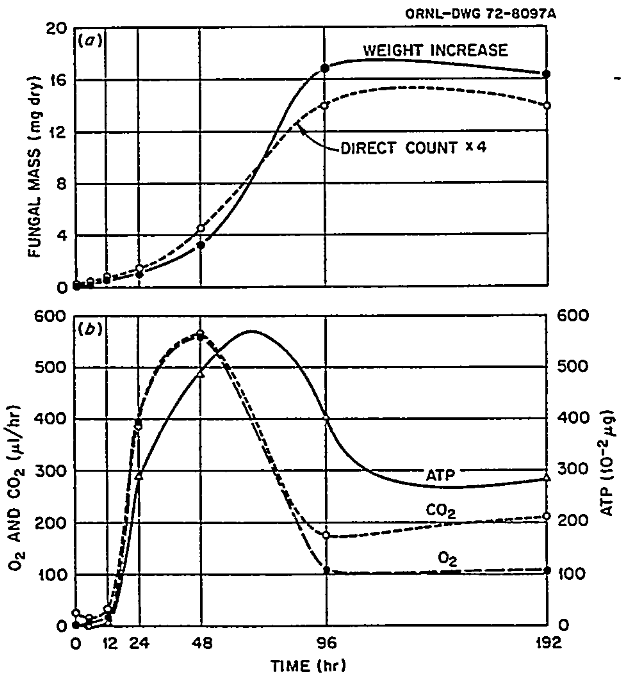

Fig. 1.3. (*a*) Estimates of fungal mass by weight increase, direct count of mycelium and spores, and loss of light transmittance from Millipore filters with fungal mass from sand cultures; (*b*) estimates of fungal activity vs ATP content of the fungal mass and rates of O_2 consumption and CO_2 evolution from sand cultures.

of a succession of two types of fungi (*Oidium* and *Aspergillus*) under favorable conditions and under stress (drought and starvation). The values of all parameters increase during the initial log phase of growth. With the onset of stress conditions, after two days the mass (Fig. 1.3*a*) remains rather constant, but activity decreases until after four days. Changes in the ATP lagged somewhat behind measures of gas exchange (Fig. 1.3*b*). However, ATP values were significantly and positively related to the activity estimate, whereas the relationship to mass estimates tended to be negative. These results, in conjunction with published data, indicate that estimates of microbial activity (Fig. 1.3*b*) can be used to describe microbial nuclide transfer, while estimates of microbial mass will reflect microbial nuclide accumulation.

2. Walker Branch Watershed: A Study of Terrestrial and Aquatic System Interaction

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The primary objective of the Walker Branch Watershed project is quantification of biogeochemical cycles in a forested landscape. To accomplish this objective, both terrestrial and aquatic ecosystems of the watershed are being studied to

1. establish quantitative relationships between the hydrologic and mineral cycles,
2. relate water quality and aquatic productivity to characteristics of the adjacent terrestrial system,
3. provide information on natural terrestrial and aquatic system interactions for comparison with those modified by cultural treatments, and
4. apply the knowledge gained from this small, controlled drainage basin study to broader landscape units to evaluate the impact of man's activities on the total ecosystem.

Walker Branch is the site of watershed research being conducted in cooperation with the International Biological Program (IBP) in the Environmental Sciences Division (see Sect. 3 of this report). As such, research effort reported in the IBP section of this report and that reported here are complementary and designed to examine similar ecosystem processes at differing levels of resolution and synthesis.

The focus of the Walker Branch Watershed project is on the nutrient elements: nitrogen, phosphorus, potassium, calcium, and magnesium. Since transport phenomena and sampling procedures for these elements and those present in trace quantities are similar, the Toxic Materials in the Environment project (see Sect. 8 of this report) is utilizing Walker Branch Watershed to characterize trace-element concentrations in major ecosystem components and establish input-output relationships for the drainage basin.

Last year's annual report[8] presented progress concerning vegetation analysis and production, nutrient concentrations in foliage and associated litterfall, biomass and nutrient content of organic soil horizons, a soil water and evapotranspiration simulation model, geology, and land use history of Walker Branch Water-

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1. Dual capacity.
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6. Plant and Equipment Division.
7. Reactor Division.

8. S. I. Auerbach et al., *Ecological Sciences Div. Annu. Progr. Rep. Sept. 30, 1971*, ORNL-4759, pp. 30–48.

shed. These sections dealt primarily with terrestrial vegetation and soil components of the ecosystem. This year our effort has expanded to also include avian, insect, and small-mammal populations as regulating factors of system processes. Research in the aquatic component of the watershed is being expanded to address interactions between land and water.

TERRESTRIAL STUDIES

Analysis of Aboveground Biomass Accumulation

A main objective of analysis of forest production of Walker Branch Watershed is to characterize variation in annual biomass accumulation as a function of several sources (e.g., species composition, site, climatic, and stage of community development) in order to estimate the accompanying mineral accumulation and subsequent recycling by vegetation. Increment core analysis of trees for the 1961–70 period was used to reconstruct patterns of biomass accumulation. The sample of increment cores included all major species from site and diameter classes representative of the study area. Relative biomass accumulation (annual biomass accumulation/total biomass) approaches a value of 2.5%, which is independent of slope for a population of trees with mean diameter >25.4 cm DBH (diameter at breast height) (Fig. 2.1). Variation in relative biomass accumulation ranged from 1.8 to 3.0% within slope class (<15%) and similarly over a range of diameters 28 to 40 cm DBH for the 1961–70 period. While relative net production of an overstory tree diameter class is independent of slope, the grouping of tree diameters indicates the influence of either slope or past land usage on tree diameter distribution. Values of relative branch-bole biomass accumulation show decreasing sensitivity to slope-class influence as tree diameters approach 15 cm DBH. Variation within slope class and DBH is similar (4 to 7%), but slope classes are grouped at DBH <13 cm (Fig. 2.1). Variation in relative biomass accumulation was greatest among sapling trees; variation in 1961 ranged from 14 to 58% among slope classes. Over the range of reconstructed diameters (4.5 to 7.4 cm DBH), relative biomass accumulation varied from 8 to 58%.

Analysis of relative biomass accumulation will both simplify and improve precision of the forest production component of the watershed model. Efforts to simulate sensitivity of overstory production to site variables will be redirected, since techniques used for estimation of overstory production inherently lack the accuracy to resolve effects of site variables within the observed range of variation in relative biomass accumulation of

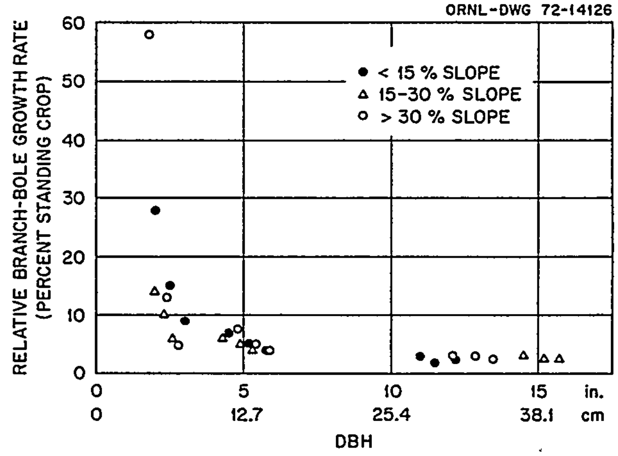

Fig. 2.1. Summary of relative branch-bole biomass accumulation reconstructed from increment core analysis for the 1961–1970 period. Values within slope class designations from left to right are mean tree diameters for 1961, 1965, and 1970 respectively. Relative growth rate was calculated by difference from bole increments at breast height for successive years and allometric analysis of diameter at breast height and aboveground tree weight. Values are means for all species sampled. Species were sampled proportionally to their density.

overstory trees. Increased precision in estimates of overstory production for various sites can be obtained only through accurate estimation of biomass and diameter densities. Improved accuracy in estimates of annual net production appear feasible for smaller-diameter classes (<15 cm DBH). In this case, relative net production is sensitive not only to size but also to site variables such as slope. Depending on the allocation of net production among diameter classes (e.g., skewed diameter distributions observed during forest stand development), real improvement in the accuracy and precision of predicting biomass accumulation can be realized through analysis of site influences on net production.

Estimation of Root Biomass

Analysis of ecosystem processes has emphasized the need for determining the role of root organic matter flux and accumulation in biogeochemical cycles of forest ecosystems. For example, lateral root turnover rates of 0.21 per year in a mesic yellow poplar forest[9] represent a large flux and subsequent sink (see Sect. 3 of this report) for mineral material on the soil exchange complex either for utilization in forest growth or simply conservation of mineral material as suggested by

9. D. E. Reichle et al., *Carbon and the Biosphere Symposium*, AEC-CONF-720510 (in press), 1972.

Odum.[10] The underground component of organic matter on Walker Branch Watershed has been analyzed for (1) standing pools of stump and large support laterals; (2) root distribution with depth for size classes of <0.5 to 1.0 cm, 1.0 to 2.0 cm, and >2.0 cm in diameter; and (3) ratios of total below- and aboveground material for the range of biomass densities represented on the study area. Analysis of mineral content (N, P, K, Ca, Mg, Na) is in progress.

The ratio of below- to aboveground biomass (R/S) ranges from 0.21 to 0.32 for forest stands with total aboveground organic matter ranging from 1.1×10^4 to 1.85×10^5 kg/hectare (Fig. 2.2). During the course of stand development (defined here as accumulation of biomass), a 68% increase in aboveground organic matter is accompanied by only a 35% increase in the belowground component. The R/S response during forest stand development suggests two hypotheses: (1) allocation of photosynthate to belowground components decreases during forest stand development or (2) the turnover rate of root organic matter increases during stand development, possibly accompanied by decreased photosynthate allocation to roots. At this stage of understanding of ecosystem processes, there are no cogent arguments for accepting either possibility. An increased turnover of root organic matter, however, is consistent with the observed trend in successional development of closing or "tightening" of biogeochemical cycles, thus reducing loss of mineral elements.[11] Both increased turnover of root organic matter and decreased allocation of photosynthate to roots are consistent with the ontogenetic shift from root storage to aboveground storage of carbohydrate[12] and the potential economy of storage of carbohydrates through sloughing of respiring root tissue during dormancy. Other workers[13] suggest an

10. E. P. Odum, *Science* 164, 262–70 (1969).

11. F. H. Bormann and G. E. Likens, *Science* 155, 424–29 (1967).

12. P. J. Krammer and T. T. Kozlowdki, *Physiology of Forest Trees*, McGraw-Hill, 1960.

13. M. S. Ghilarov et al. (eds.), *Methods of Productivity Studies in Root Systems and Rhizosphere Organisms*, International Symposium, U.S.S.R., IBP Central Office, London, 1968.

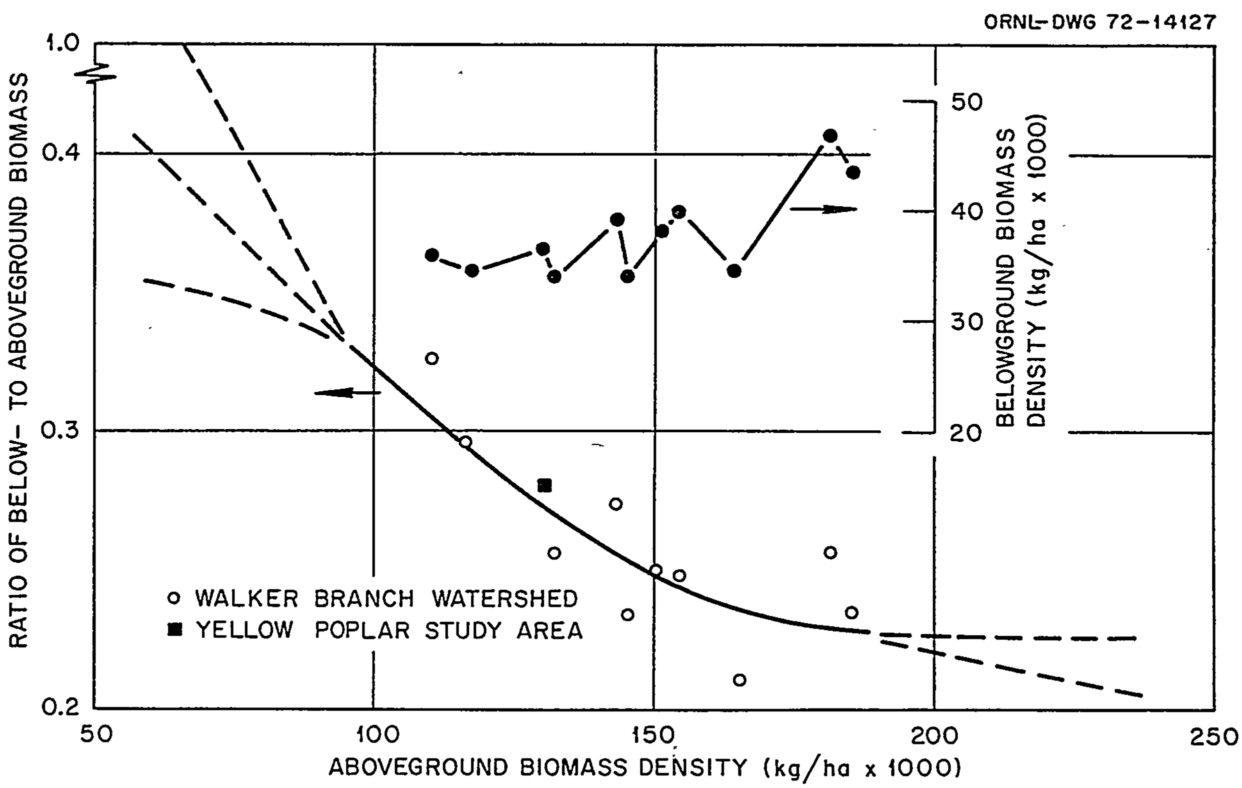

Fig. 2.2. Distribution of below- to aboveground biomass ratios with total aboveground biomass (curve hand-fitted). Total belowground biomass (right-hand scale) includes the central tap root, large support laterals to a radius of 60 cm from the tap, and small lateral root biomass to the depth of the rooting zone, which ranged from 40 to 60 cm.

equilibrium ratio of below- to aboveground biomass of 0.25, which the stands on Walker Branch are approaching. Analyses of stands beyond the range thus far examined are in progress to determine the trend of these ratios during early stand development and to test the hypothesis that equilibrium occurs late in forest stand development.

Influence of Forest Type on Litterfall

In last year's annual report, data on nutrient return via litterfall in four forest types on the watershed were presented.[8] Since then, canonical analysis has been employed to distinguish differences in litterfall between the four forest types. By using multivariate canonical analysis, seven measurements (weight and N, P, K, Ca, Mg, and Na content) may be reduced to a vector of only two measurements which are independent of each other. For each litterfall component (leaves, limbs, and reproductive parts) and the total litterfall, the first two canonical variates for each forest type are derived and plotted two-dimensionally as point coordinates (Fig. 2.3). In addition, confidence circles may be drawn around each point, and these may be used to make inferences about the different forest types.

In Fig. 2.3*a* a plot of the first two canonical variates (y_1 and y_2) for the mean vectors of the leaf litter component from each forest type is given along with 95% confidence circles. Pine and pine-oak-hickory forest types do not differ significantly. However, the oak-hickory and mesophytic hardwood types differ significantly from each other and also from both pine and pine-oak-hickory. In Fig. 2.3*b* a similar plot is given for the limb litter component. Pine, pine-oak-hickory, and oak-hickory do not differ significantly, but the mesophytic hardwood type differs from pine-oak-hickory and oak-hickory. In Fig. 2.3*c*, where litter from reproductive parts is considered, pine differs significantly from the other three forest types. The general overlapping of the confidence circles for pine-oak-hickory, oak-hickory, and mesophytic hardwood indicates no essential difference in litter from reproductive parts among these three forest types. Total litter from leaves, limbs, and reproductive components was combined, and the first two canonical variates from the mean vectors for each forest type were plotted along with the associated 95% confidence circles (Fig. 2.3*d*). Pine and pine-oak-hickory differ significantly from oak-hickory and mesophytic hardwood, but pine and pine-oak-hickory do not differ significantly from each other. Oak-hickory and mesophytic hardwood also differ significantly from each other.

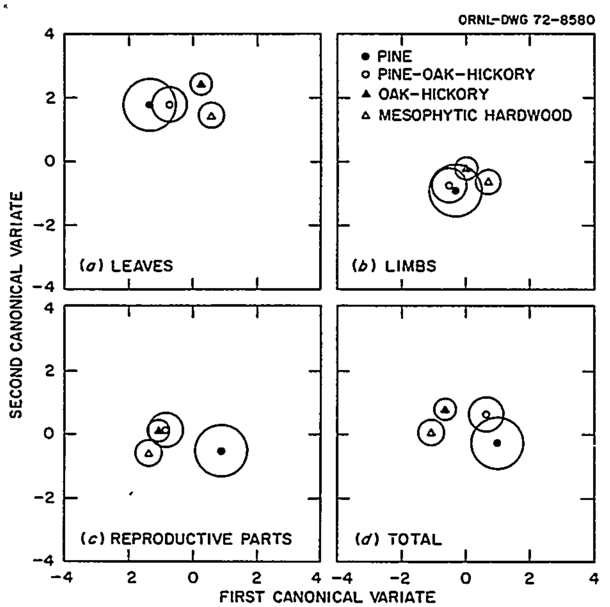

Fig. 2.3. Mean canonical points with 95% confidence circles for litterfall components in four forest types.

Canonical analysis of litterfall components using nutrient and biomass measurements simultaneously allows us to identify major differences and/or similarities in cycling patterns due to forest type. Whereas pine and pine-oak-hickory stands are similar with respect to total litterfall, oak-hickory and mesophytic hardwood stands generally behave differently from the other stand types. These differences are primarily associated with differences in biomass and nutrient return of the foliage component of litterfall. Thus further effort on characterizing stand differences in nutrient return dynamics will be concentrated on the foliage component and that associated with reproductive parts in the case of pine stands.

Nitrogen and Phosphorus Fertilization Effects on Decomposition of White Oak Leaves

Decomposition processes are responsible for regulating nutrient cycles within ecosystems and thus play an important role in maintaining productivity of forest stands. Since fertilization of the watershed with urea and superphosphate is one of the possible perturbations which may be used to test our understanding of nutrient cycles, a study of the effects of these two fertilizers on decomposition processes was undertaken. White oak leaves in nylon litter bags were placed on the forest floor in the fall of 1970 in a 3 X 3 factorial plot design of urea and triple superphosphate addition.

Fertilizer was added in March 1971, at rates of 0, 550, and 1100 kg/hectare nitrogen and 0, 275, and 550 kg/hectare phosphorus.

The interaction of nitrogen and phosphorus increments on percent litter weight loss is shown in Fig. 2.4. Phosphorus additions generally inhibited decomposition, whereas nitrogen enhanced litter breakdown. Only one treatment, the highest nitrogen level, resulted in decomposition rates greater than those for the control. For other treatment combinations, effects of phosphorus addition usually suppressed the effects of added nitrogen.

These results suggest that nitrogen fertilization would accelerate decomposition and, therefore, release of nutrients from organic soil horizons and loss from the soil system. If phosphorus is added in conjunction with nitrogen, increased decomposition and potential for nutrient loss are not observed. However, it is not sufficient to look at litter breakdown rates alone. Other data suggest that microorganism populations increase and become an important buffer to nutrient loss following nitrogen fertilization. These elevated populations may persist for some time due to the more favorable nitrogen availability and then gradually decrease with a commensurate buildup of organic horizons. Thus the importance of litter and its associated microorganisms as a nutrient conservation mechanism changes as nitrogen and phosphorus availability is altered.

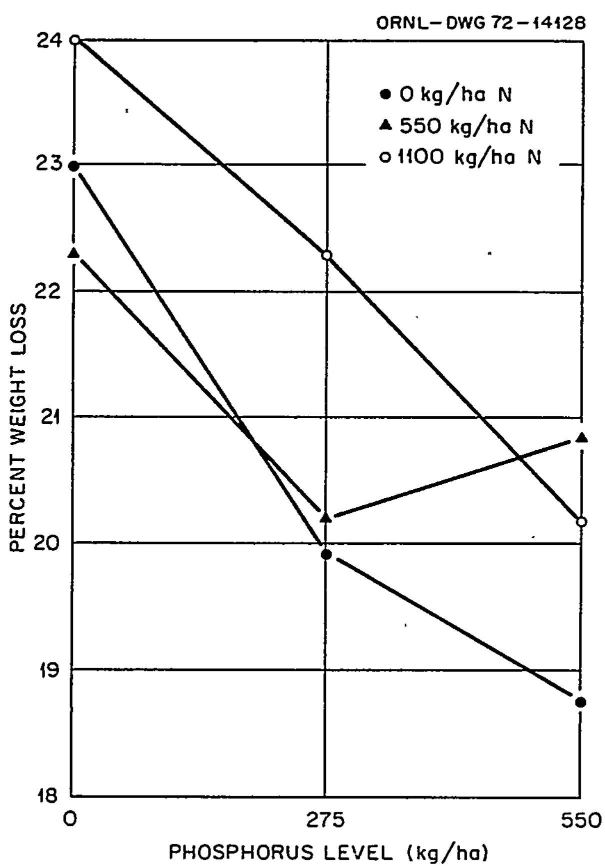

Fig. 2.4. Effect of nitrogen and phosphorus fertilization on decomposition (percent weight loss) of white oak leaves.

Nitrogen, Phosphorus, and Potassium Pools and Fluxes in Oak-Hickory Stands

Vegetation and soil are the two major nutrient pools in terrestrial portions of forested ecosystems. Both must be quantified in order to characterize nutrient cycles. The vegetation pool has two components: (1) leaves and small roots, which play an important role in annual nutrient cycles, and (2) bole, branch, stump, and large roots, which constitute a longer term store of nutrients. The soil, including the forest floor, also acts as a long- and short-term storage medium for nutrients. Nitrogen, phosphorus, and potassium pools and the major fluxes are summarized for components of a typical oak-hickory stand on Walker Branch Watershed (Table 2.1).

Nitrogen, phosphorus, and potassium are distributed similarly in vegetation, although the absolute amounts are quite different. Approximately 65% of the respective element pool is incorporated in large woody material (bole, branch, stump), while foliage and roots contain approximately 13 and 22% of the total respectively. Within the total terrestrial pool, vegetation stores 11% of the nitrogen, 4% of the phosphorus, but less than 1% of the potassium. Within the forest floor the O_1 and O_2 horizons are the most important nutrient reservoirs. A greater portion of nitrogen, phosphorus, and potassium in soil occurs in mineral soil horizons than in organic horizons. Much of the nitrogen and phosphorus is held in organic complexes, while nearly all potassium is in the form of inorganic primary and secondary minerals.

Root mortality is the most important mechanism for recycling of all three elements from vegetation to soil. Litterfall, followed by throughfall leaching, is the next most important cycling mechanism for nitrogen and phosphorus. The relative importance of these two mechanisms is reversed for the more mobile potassium. The return of nitrogen, phosphorus, and potassium in branch and bole material is insignificant compared with other transfers but does represent a long-term pool on the forest floor. The annual uptake of these elements (equal to the sum of litterfall, throughfall, root mor-

Table 2.1. Pool sizes and annual transfer rates of nitrogen, phosphorus, and potassium in oak-hickory stands on Walker Branch Watershed

	Nitrogen	Phosphorus	Potassium
Nutrient pools			
In kilograms per hectare			
Vegetation			
Foliage	53	5	42
Branch	120	10	51
Bole	164	11	110
Stump	37	2	24
Root	104	10	45
Total	478	38	272
Forest floor			
Wood >2.5 cm	28	2	6
Twig <2.5 cm	9	<1	1
O_1 horizon	88	6	7
O_2 horizon	179	12	14
Total	304	20	28
Mineral soil[a]	4000	950	32,500 (140)[b]
Nutrient transfers			
In kilograms per hectare per year			
Litterfall[c]	36	3	20
Bole and branch mortality	1	<1	1
Root mortality	72	7	32
Throughfall	13	<1	24
Incorporation in growth	7	<1	4

[a]To 60 cm depth.
[b]Exchangeable potassium on the basis of 1 *N* ammonium acetate extraction in parentheses.
[c]Includes leaves, twigs <2.5 cm in diameter, and reproductive parts.

tality, and incorporation in growth) results in an annual retention in vegetation components of only 5% of uptake.

Nitrogen and phosphorus are more tightly coupled in organic complexes than potassium. Thus decomposition processes play an important role in recycling nitrogen and phosphorus but are less important for potassium. In contrast to potassium, which is present in large quantities in the soil matrix, cycling processes tend to conserve the more limited nitrogen and phosphorus through organic complexes, which are relatively immobile in terrestrial systems and are only slowly released for uptake by vegetation.

Habitat Utilization and Functional Role of Avifauna

To assess the role of avifauna and characterize their utilization of the habitat on Walker Branch Watershed, sample counts were made during June and July on the 24 core vegetation plots. Counts were made by recording the birds present at 5-min intervals. The strata of activity in the canopy, sex, and age of each bird present were recorded. A total of 1549 observations were made. Forty avian species were recorded, of which 16 were dominant components of the fauna.

Birds are known to select habitat on the basis of gross sign stimuli of the habitat, which presumably convey information on factors (e.g., food, nest site availability) necessary for the birds' immediate survival. These sign stimuli are some aspect of the vegetational physiognomy. Once a bird occupies a particular habitat, key factors within that area are important in determining where it spends its time. On a macrolevel, the stratification pattern shows how birds utilize and recognize different vegetation types.

When the stratification of birds was examined by core vegetational type, it was found that the pine and tulip poplar communities had distinct avian stratification patterns, while the chestnut oak and oak-hickory communities had very similar stratification patterns (Fig. 2.5). The total bird population was dividing the watershed into three habitat types. To examine individual species and their utilization of these habitats on a microlevel, each bird species was compared with 28 vegetational variables. As an initial step in a multivariate analysis of these data, an analysis of variance was performed, testing for significant differences among plots where birds of a given species were found present, absent, or present in numbers greater than one.

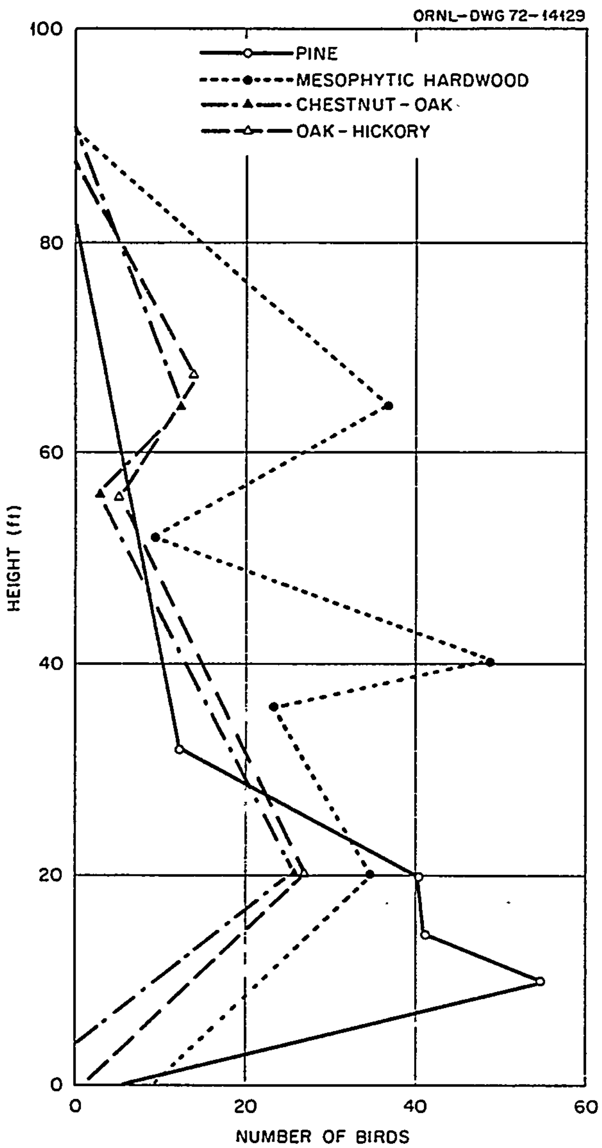

Fig. 2.5. Vertical stratification of breeding birds in four forest types on Walker Branch Watershed.

The results of these analyses for eight common bird species and ten vegetational variables are shown in Table 2.2. Some birds, such as the western wood pewee, red-eyed vireo, and Carolina wren, show a significant degree of selection for many of the variables tested. Essentially, they are specialists, spending most of their time on areas with the appropriate vegetation structure. The Carolina chickadee, tufted titmouse, and summer tanager are generalists, which select for very few variables and thus are found in most parts of the watershed. Were the vegetation to be altered (e.g., by removal of all trees over 8 cm DBH, or by a forest fire), many of the specialists would no longer find the appropriate variables and would not use the area. Other birds more adapted to open areas (e.g., chipping sparrows) would become residents. The summer and scarlet tanagers, two congeneric species, show a great deal of difference in their selection for vegetational variables. Both are present in equal numbers, but the scarlet tanager is much more specialized. Both the Carolina wren and the hooded warbler nest and forage in the dense shrub vegetation; however, the wren is much more selective. This is very apparent to the observer, who can see many hooded warblers on a tour of the watershed but seldom sees the Carolina wren.

Birds are known to be very selective predators. Their choice of foods depends on their past experience, foraging pattern, morphological variations, and social behavior. Dominant insect species and seeds are not necessarily the choice prey item for birds; thus one must make a dietary analysis of birds inhabitating an area to assess the impact of the avian population on plant propagules and arthropods. Such a study is presently under way on four of the dominant bird species: the Carolina chickadee, tufted titmouse, Carolina wren, and red-eyed vireo.

Density and Biomass of Canopy Arthropods

As part of the Secondary Production studies on Walker Branch Watershed, a sampling program was initiated to determine density and biomass of the arthropods present in the forest canopy. The objectives of this survey were to (1) establish a list of the major taxa occurring on the foliage and (2) determine density and biomass exchanges through important taxa and trophic levels. Data from this project will be integrated with studies of bird, mammal, and forest floor arthropod populations in an analysis of the terrestrial secondary producer portion of this watershed system.

Since the watershed canopy consists of a variety of tree species, the five dominant types in terms of basal area coverage were sampled. Five individuals each of chestnut oak, white oak, hickory, tulip poplar, and shortleaf pine were randomly selected on each date from previously marked trees in the watershed. Two leaf clusters from each tree, randomized by aspect, were collected weekly during the summer of the 1972 growing season. Leaf clusters were obtained in a 1-m^3 plastic bag at approximately 8 m height. Arthropod density and biomass were reported as number and weight per square meter of leaf surface area. When leaf area indices become available for each of these species, these results will be converted to square meters of ground surface.

There are seven major groups of arthropods present in the watershed canopy (Table 2.3). Absence of dipterous and hymenopterous insects would indicate that this sampling technique is not adequate for the more mobile species. The data indicated that in each of the five major tree types, Lepidoptera larvae had the highest biomass. Orthoptera and Coleoptera were the next most dominant forms, with a single weevil species being responsible for the high Coleoptera biomass. The most numerous individuals were aphids. Chestnut oak and tulip poplar supported almost twice the total arthropod biomass that occurred on the other tree species. Although temporal variations in canopy arthropod numbers and biomass are not available presently, the data on mean summer numbers and biomass (Table 2.3) give indication as to which groups will require intensive sampling on the various tree species.

Table 2.2. Vegetation variables which were of significance to selected birds

Variable	Tree size (cm DBH)	Eastern wood pewee	Carolina chickadee	Tufted titmouse	Carolina wren	Red-eyed vireo	Hooded warbler	Scarlet tanager	Summer tanager
Foliage biomass	1.2–8.4	*					*		
	8.4–22.8	*			*			*	
	>22.8				*	*		*	
Branch biomass	1.2–8.4	*	*			*	*		
	8.4–22.8	*			*			*	
	>22.8				*	*		*	
Bole biomass	1.2–8.4	*	*			*	*		
	8.4–22.8	*			*			*	
	>22.8				*	*		*	
Plot slope		*				*			*

*Significant at 0.05 level.

Table 2.3. Mean summer density and biomass of the major canopy arthropods in Walker Branch Watershed during the 1972 growing season

Values represent means obtained from seven weekly samples. Densities are numbers of individuals per square meter of leaf surface; biomasses are in milligrams dry weight per square meter of leaf surface

	Tulip poplar		Shortleaf pine		Hickory		Chestnut oak		White oak	
	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass
Coleoptera	7.2	12.6	4.3	10.2	3.8	8.9	7.5	17.7	3.7	8.8
Hemiptera	3.6	0.7	6.4	1.2	4.0	0.8	9.3	1.8	4.2	0.8
Homoptera	89.6	7.5	15.2	4.3	9.1	2.6	5.2	1.5	7.9	2.3
Lepidoptera	4.1	20.8	5.2	26.1	2.6	13.1	7.5	37.8	6.9	34.5
Neuroptera	2.2	0.9			2.3	0.9			1.9	0.7
Araneida	6.2	8.4	3.8	1.4	7.0	2.5	6.8	2.4	4.2	1.5
Orthoptera	4.0	17.6	1.2	5.3	3.0	11.5	2.3	10.1		
Total	116.9	68.5	36.1	48.5	31.8	40.3	38.6	71.3	28.8	48.6

Functional Role of Small-Mammal Populations

Small-mammal trapping was conducted on Walker Branch Watershed during July 1972. Two hundred ten Sherman live traps were distributed over a 1.3-hectare area of mature mixed oak-hickory forest. Objectives of this preliminary trapping work were to determine species abundances and recapture frequencies. Species recorded in 288 captures included: *Peromyscus leucopus* (193), *Tamias striatus* (49), *Microtus pinetorum* (36), *Glaucomys volans* (5), and *Blarina brevicauda* (5). *Sciurus carolinensis* was observed on the site but not trapped. Fifty-eight animals were marked: *Peromyscus* (31), *Tamias* (11), *Microtus* (12), *Glaucomys* (3), and *Blarina* (1). There were 146 recaptures of marked animals, including 94 *Peromyscus*, 32 *Tamias*, 19 *Microtus*, and 1 *Glaucomys*.

Seasonal estimates of species composition and population sizes are essential to three related Walker Branch Watershed small-mammal studies: ecological segregation, population energetics, and control functions. Results of these studies, when expressed quantitatively at the population level, facilitate an evaluation of the functional roles of the small mammals in a temperate deciduous forest. Such evaluations allow more realistic assessments of possible effects of various ecosystem perturbations.

AQUATIC STUDIES

During the past year, aquatic studies have emphasized the determination of the sources and utilization of carbon by benthic macroinvertebrates in Walker Branch. This information will be incorporated into a series of physiological process models and will provide base-line data on secondary productivity within the aquatic ecosystems. Ultimately, this information will contribute to the carbon budget of the entire watershed. The primary energy source for the biota of the stream is litterfall (allochthonous detritus) from the surrounding forest. An evaluation of the carbon sources of the dominant primary consumers in the stream has commenced and will continue throughout the next year. Included in this study are leaching and breakdown rates of leaves of dominant tree species entering the stream and their effect on the total nutrient pool (C, N, P, K, Ca, Mg, Na) available to the stream biota. Quantitative sampling of the benthic macroinvertebrates is in progress to determine their sources of carbon, species composition, and seasonal diversity within the watershed streams. Preliminary surveys have shown that three primary consumer species (a snail, *Goniobasis clavaeformis*; stone fly, *Peltoperla maria*; and mayfly, *Ephemera guttulata*) make up the majority of the animal biomass, with the remainder being apportioned among at least 66 other species. The snail is a grazer and feeds on periphytic algae, while the other two species are detritus feeders.

Laboratory and field experiments are in progress to evaluate the ingestion, egestion, assimilation, and turnover rates of carbon by these species. These involve feeding of single (^{14}C) or dual (^{14}C plus ^{144}Ce) tagged detritus to the organisms and subsequent analysis for the presence of the tracer in the organisms and their excreta. In order to characterize the total carbon utilization by the primary consumers of the stream, it is necessary to know the fraction involved in metabolic activities of the organisms. Diurnal oxygen determinations using the Winkler method were run to measure the metabolism of the aquatic community. These were done at two sites in the West Fork (200 and 900 ft above the weir) and in the primary spring (800 ft above the weir) on the West Fork. The data show that the spring is approximately 70% saturated with oxygen, while the stream sites are about 85% saturated (Fig. 2.6). There were slightly lower dissolved oxygen and water temperature readings for the upper stream station. Figure 2.6 shows temperature and dissolved oxygen levels (not corrected for diffusion) for two 24-hr periods for a site on the stream and the primary spring on the West Fork. These data suggest that primary productivity within the system is low, which confirms results on primary production in this stream obtained by a different method.[14] At present, equipment is being installed that will allow electrometric determination of dissolved oxygen and temperature at two sites at 10-min intervals over a 72-hr period. These data should provide insight into the contribution of primary producers to the system and will supplement the information on aquatic metabolism being obtained by the Winkler technique.

HYDROLOGIC STUDIES

Flow Characteristics of the East and West Forks

A basic requirement for the utilization of Walker Branch Watershed as a site for paired-watershed studies is the correlation of hydrological characteristics of the East and West Forks. One of the problems encountered

14. J. W. Elwood and D. J. Nelson, "Periphyton Production Rates and Grazing Rates in a Stream Ecosystem Using a Material Balance Method," *Oikos* (in press).

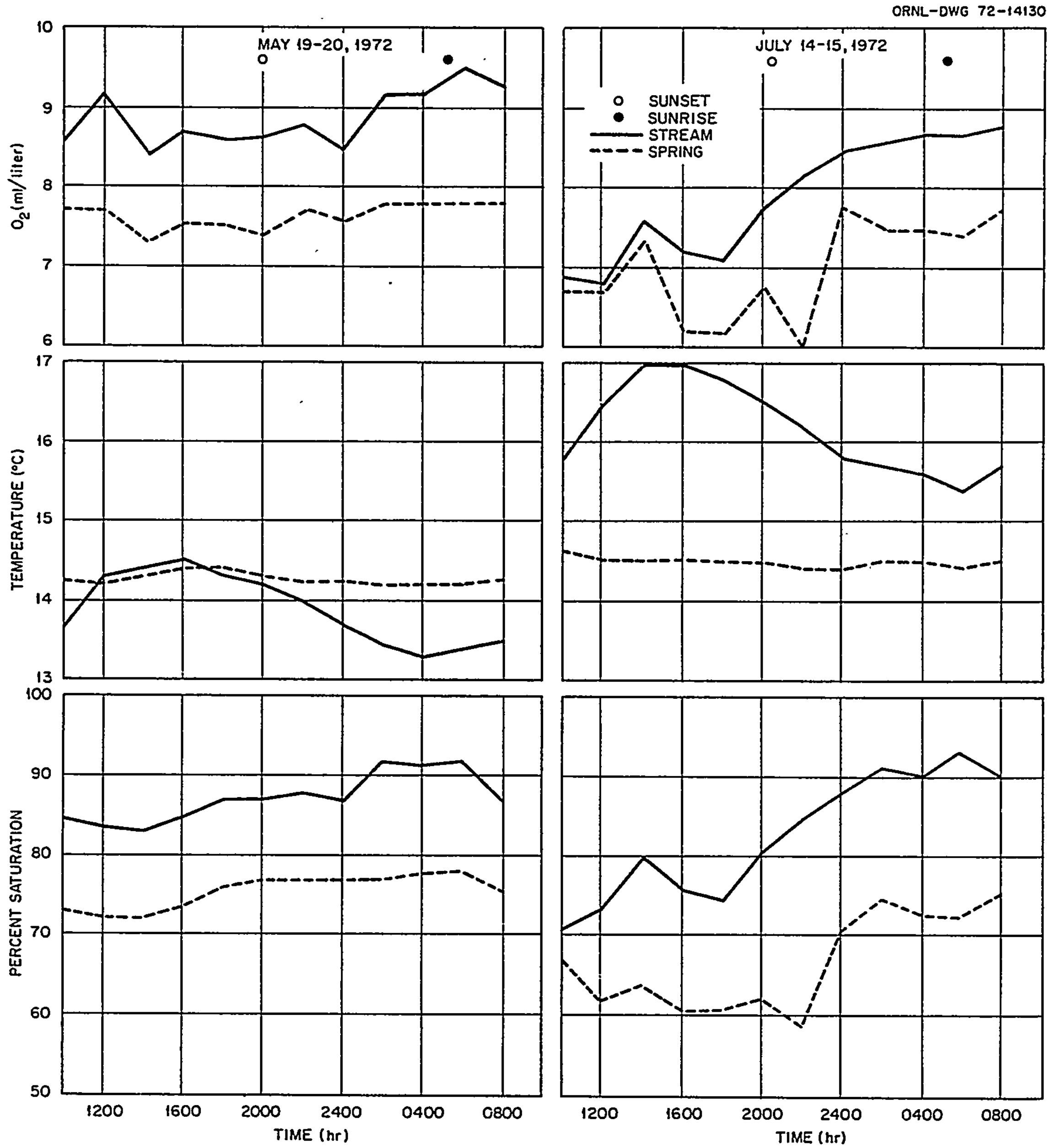

Fig. 2.6. Dissolved oxygen, temperature, and percent oxygen saturation during 24 hr at two sites on the West Fork, Walker Branch. Oxygen values have not been corrected for diffusion.

in the process of "calibrating" the watershed is the significant difference in stream flow of the two forks at low stream flow rates. For example, during seasons with relatively little precipitation, the weekly mean flow rate of the East Fork (58-hectare catchment) has been as low as 0.01 cfs, while corresponding stream flows of the West Fork (39-hectare catchment) were never less than 0.14 cfs. For stream flows of the order of 1 cfs and greater, the ratio of stream flow on the West Fork to that on the East Fork approximates the ratio of the respective catchment areas.

When the East Fork stream flow is less than about 0.1 cfs, flow is subterranean along two reaches. The stream goes underground ~435 m from the weir and discharges at spring S1E at 285 m from the weir. Then the stream goes underground again ~220 m from the weir and emerges in a spring in the east settling basin ~30 m from the weir. A possible explanation for the observed low stream flow at the east weir is that during the underground excursions, part of the East Fork stream flow is diverted to the West Fork or out of the bounds of the watershed.

We have utilized tracer techniques as a preliminary step toward elucidating the peculiarities of the East Fork stream flow. Rhodamine B dye and a solution of calcium chloride were injected into the stream at a small 100° V-notch weir, 488 m above the East Fork weir. Stream flow at spring S1E was about a factor of 5 greater than that at the east weir, and flow at the west weir was about a factor of 30 greater than that at the east weir.

The stream was sampled 437 m from the weir (just above the point where the flow first goes subterranean), at the primary spring S1E, and at the spring that discharges into the East Fork stilling basin. The east stilling basin was drawn down for the tests. Samples were also taken on the West Fork at the primary spring (S3W), the stream just above S3W, and the stream feeding the West Fork stilling basin. Chloride concentrations of the samples were determined by amperometric titration. Figure 2.7 shows the chloride concentrations as a function of time at several sites on the watershed. Approximately 29 hr elapsed from the time the tracer entered the first subterranean reach of the East Fork until it was detected in spring S1E, and about 53 hr elapsed before the tracer was detected in the spring discharging into the settling basin.

The gradual tailing off of the chloride concentrations shown in Fig. 2.7 is a typical result of stagnant pools between the point of tracer injection and sampling and lends considerable uncertainty to the material balance. However, conservative estimates indicate that at least 65% of the chloride injected into the stream was in the effluent of spring S1E, while only ~8% of the original tracer was discharged into the east stilling basin. Further, there was no detectable change in the chloride concentration of spring S3W or of the west stilling basin. These results suggest that a significant amount of the East Fork stream flow was diverted beyond the watershed boundary in the reach of subterranean flow that extends from 220 to 30 m from the east weir.

Input-Output Relationships

During the year it was discovered that our basic computer program for converting stage height and precipitation gage recordings to stream flow and precipitation was not functioning properly. The errors in this program have recently been corrected, and the program has been expanded to include elemental analyses. Revised hydrologic and element budgets will be forthcoming in the near future.

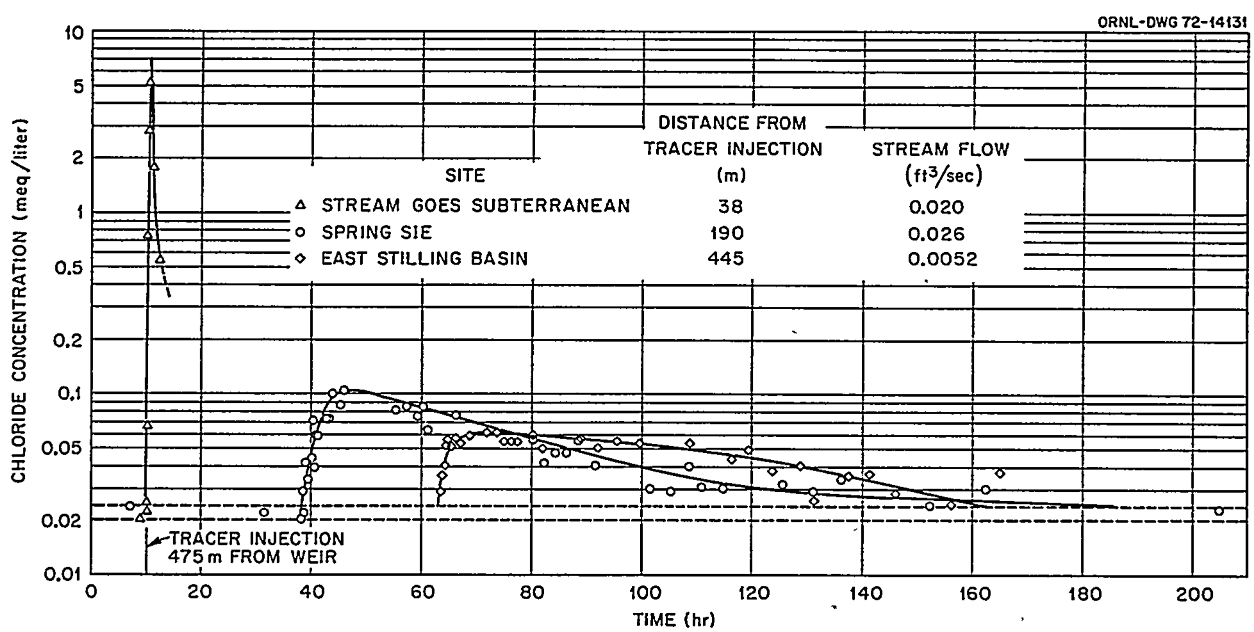

Fig. 2.7. Change in chloride concentration with time at various sites on the East Fork of Walker Branch Watershed following calcium chloride release. Time scale begins 0:00 hr August 29, 1972.

3. International Biological Program: Oak Ridge Site

D. E. Reichle[1]

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M. Breed[4]	B. A. Hutchison[6]	M. H. Shanks[1]
T. Cox[2]	J. B. Mankin[3]	S. Y. Shieh[5]
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The Oak Ridge Site of the Eastern IBP Eastern Deciduous Forest Biome is concerned with the analysis of forest ecosystems, including both the functional characteristics and relations which govern the dynamics of these systems. The program is structured to examine coupled terrestrial and aquatic systems based on a research program executed at sequential scales of complexity. Analysis of the processes and components of specific ecosystems permits evaluation of the significance of these processes and consequences of their modification and alteration to total system behavior. Research on the basic ecological processes which regulate forest ecosystems is being obtained to provide comparative data on the productivity and mineral cycling of forested ecosystems — their dynamics, stability, and internal control factors. Pathways and rates of transfer of energy and materials among the components of these systems are being identified and quantified. Emphasis is being placed on the concomitant development of (1) mechanistic models of ecosystem processes; (2) the coupling of process models leading to construction of dynamic ecosystem models of carbon, water, and nutrient elements; and (3) the integration of terrestrial and aquatic ecosystem models at the spatial scale of watersheds.

The research program and systems modeling emphasize variables most likely to vary across the Biome — such as microclimate, soils, and differences in species composition. Emphasis is being placed on increasingly more general models with wider applicability as our understanding of ecosystem components and processes evolves. These models are based upon two basic "carrier systems" — biomass (carbon) and water. Research at the Oak Ridge Site will proceed at three scales of environmental complexity: ecological process, ecosystem, and watershed. Mathematical models are being developed to aid in the design and coordination of research projects, as an analytical tool to study behavior of intact systems, and to permit predictions of system response to perturbation. At the process level, research is concentrating on physiological processes such as photosynthesis, transpiration, decomposition, and animal grazing. At the ecosystem level, flows and cycles of

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carbon, water, and nitrogen, phosphorus, potassium, and calcium are being considered. Models will include data on the effects of solar radiation, temperature, precipitation, and mineral inputs as driving variables on system processes. At the watershed level, changes in water and mineral output from Walker Branch Watershed will be simulated based on seasonal variation in meteorological and ecological variables. Since Walker Branch is an important validation site for IBP ecosystem analyses, additional information relative to our overall IBP research program will also be reported in Sect. 2 of this report.

METEOROLOGICAL RESEARCH

Distribution of Solar Radiation in a Forest

Meteorological research for the IBP project is performed by the collaborating staff of the NOAA Atmospheric Turbulence Diffusion Laboratory in Oak Ridge. During the past year, the distribution of solar radiation within a *Liriodendron* forest was measured on a relatively continuous basis. Measurements of total radiation and of diffuse radiation were made at three levels within the forest (upper canopy, midcanopy, and forest floor) and above the canopy. Measurements within the forest were replicated in space in order to ascertain the spatial variation in radiation. By repeating these measurements periodically in time, the temporal variation in radiation distribution was assessed. All data were digitized and recorded on punched paper tape.

Since data have been collected relatively continuously, we have generated a massive amount of data. These data are presently being reduced and analyzed, although no complete summary is yet available. Computer programs have been developed which allow conversion of raw data (millivolt signals) to engineering units (langleys/min), editing of these data, and writing of these data on magnetic tape. With the acquisition of a high-speed punched paper tape reader by the ORNL computer center, data reduction is now proceeding smoothly. (Data have been converted, edited, and written on magnetic tapes for August–December 1971 and for April, June, July, and August 1972 as of this time.) Some summarization programs have also been developed and data summarization made. (For example, hourly averages of total and diffuse radiation above and within the forest are available on magnetic tape for August–December 1971.)

To relate radiation distribution in this forest to forest structure, it was necessary to characterize the structure of the forest. A plane-table survey of the study area has been made, and all vegetation exceeding 1.5 m in height has been mapped. Each plant was identified as to species, and its DBH, total height, and height to first branch measured. In addition, canopy structure is being assessed using hemispherical canopy photographs. These photos are being interpreted by using a spiral reader to digitize the information contained on the photographs and by developing computer programs which will summarize this information in the form of average space and size distribution of canopy holes over the entire canopy and along the apparent solar path for selected days during the growing season.

Equipment has been acquired that will enable us to study the complete energy budget of this forest rather than just the penetration of solar radiation. A network of thermistors has been installed, and some data have been collected of temperature distribution within this forest. Dew cells have been acquired and are being readied for installation. Finally, a computer-centered data-acquisition system has been designed by the Instrumentation and Controls Division of ORNL which will allow improved data collection. Components for this system have been acquired, and assembly of the system is in progress.

Phenology of Forest Development

The relationship between the thermal environment (temperature summation) and date of first flower for 133 indigenous taxa provides significant predictability of the beginning of the reproductive phases between species. Silver and red maple are the first species to begin reproductive phases at a period when the mean daily air temperature is approximately 10°C; such a significant correlation ($r^2 = 0.99$) suggests that observations of mean date of first flower spanning several years are sufficient to estimate advent of the reproductive phase. Thermal or temperature summations utilizing daily maximum and minimum temperatures provide a precise estimate of flowering date from temperature summations, TS, such that

$$\mathrm{TS}_i = \sum_{k=1}^{i} \mathrm{adt}_k ,$$

where adt_k is the average daily temperature:

$$\left(\frac{\text{maximum temperature} + \text{minimum temperature}}{2}\right).$$

Since the relationship between species is significant, the predicted date of first flower (year day) may indicate

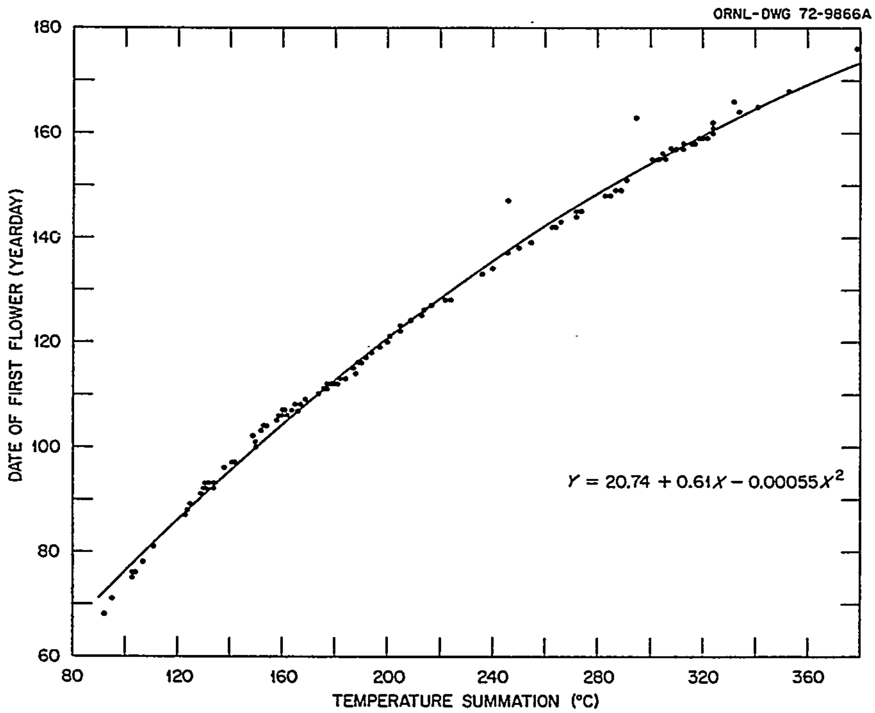

Fig. 3.1. Relationship between mean date of first flower and mean temperature summation (1963–1970). Points represent various species at the Oak Ridge site.

minimum or threshold thermal regimes necessary to initiate the reproductive phase (Fig. 3.1).

Moisture, light, and temperature interactions are known to enhance or delay timing of certain phenological events. Departures from normal environmental conditions can alter the appearance of various phenological events within forest ecosystems as indicated by the response of flowering to temperature differences. Deviations in micrometeorological parameters, in turn, influence the timing of other dynamic characteristics of the ecosystem, such as availability of food base to secondary producers, pollination, and rates of productivity and decomposition.

CARBON FIXATION AND PHOTOSYNTHATE TRANSLOCATION

Analytical Model of Net Photosynthesis[12]

One of the major goals of terrestrial productivity studies within the IBP is the development of a series of models capable of predicting carbon assimilation rates at various levels of resolution, ranging from CO_2 fixation by individual leaves to that for entire plant communities. Photosynthesis may be considered in terms of two basic processes: physical diffusion of CO_2 to chloroplasts and biochemical fixation of atmospheric CO_2.

The first of these processes may be described according to Fick's law by an equation of the form[13]

$$P = \frac{C_o - C_i}{R} = \frac{1}{R}(C_o - C_i)\,, \qquad (1)$$

where P = net photosynthesis (mg dm^{-2} hr^{-1}), C_o = external and C_i = internal CO_2 concentrations (mg/dm^3), and R = external resistance to CO_2 flux (hr/dm).

Whereas external CO_2 concentrations and external resistance are largely physical in nature, internal CO_2 concentrations (C_i) are dependent upon both physical and biochemical processes. A model for net photosynthesis as affected by four principal factors – light, temperature, CO_2 concentration, and stomatal and boundary layer resistance – may be derived by defining C_i and substitution into Eq. (1).

12. Developed by K. L. Reed, US/IBP Coniferous Forest Biome, University of Washington, Seattle, Wash.

13. P. Gaastra, "Photosynthesis of Crop Plants as Influenced by Light, Carbon Dioxide, Temperature, and Stomatal Diffusion Resistance," *Meded. Landbouwhogesch. Wageningen* 59(11) (1959).

Internal CO_2 concentration (C_i) is the algebraic sum of three fluxes: (1) flux of CO_2 into the leaf, (2) flux from intercellular spaces to mesophyll cells (photosynthesis), and (3) flux from cells to intercellular spaces (respiration). Thus intercellular CO_2 concentration may be expressed as:

$$C_i = RF + r_w W - r_p P_i , \tag{2}$$

where $F = CO_2$ flux (mg dm^{-2} hr^{-1}), r_w and r_p = internal resistances to CO_2 transfer (hr/dm), W = mitochondrial respiration, and P_i = gross photosynthesis.

An expression for C_i may be written in terms of net CO_2 flux by subsumming mitochondrial respiration, photorespiration, and internal resistances to CO_2 transfer into an expression for internal net photosynthesis (P'_i):

$$C_i = RF - P'_i . \tag{3}$$

Internal photosynthesis (P'_i) may be defined as a function of light, temperature, and CO_2 concentration. Interactions of light and temperature may be represented by a modified Michaelis-Menton equation:[14]

$$P'_i(L,T) = \frac{P_T L}{L + K_L} , \tag{4}$$

where P_T = maximum photosynthesis at optimum temperature, L = light intensity (ergs dm^{-2} hr.$^{-1}$), and K_L = light intensity at which $P'_i(L,T) = P_T/2$. This equation describes a series of curves to which actual CO_2 measurement data may be fitted in order to obtain $P'_i(L,T)$.

Internal photosynthesis at any temperature (T) and light (L) may also be written as a function of internal CO_2 concentration:

$$P'_i = \frac{P'_i(T,L) C_i}{C_i + K} , \tag{5}$$

where $K = CO_2$ concentration at which $P'_i = P'_i(T,L)/2$.

In order to obtain C_i, Eq. (3) may be solved for P'_i and set equal to Eq. (5):

$$\frac{P'_i(T,L) C_i}{C_i + K} = RF - C_i , \tag{6}$$

resulting in a quadratic expression for C_i of the form $aC_i^2 + bC_i + c = 0$,

where

$$a = 1,$$

$$b = P'_i(T,L) - (RF - K),$$

$$c = -KRF.$$

The positive root of Eq. (6) may be substituted into Eq. (1), giving a relatively complete model for net photosynthesis.

An independent comparison of the predictive capabilities of the model is shown in Fig. 3.2. Measured net photosynthetic rates and solar radiation intensities are compared with predicted photosynthetic flux over the interval 8 AM to 7 PM, August 19, 1971. There appears to exist a slight tendency for overestimation of net CO_2 influx. This overestimate may be a result of several factors; chief among these are underestimation of external resistance to CO_2 diffusion resistance (R) and/or internal CO_2 concentration (C_i), the latter by way of uncertainties associated with estimating photorespiration. Further research efforts are being devoted to resolution of uncertainties involved in approximating these parameters. Carbon dioxide exchange data from other species will aid in evaluating the potential for using the above types of predictive equations as input functions for general productivity models.

Translocation of Photosynthate

An understanding of allocation of photosynthate among autotroph components and processes, particularly utilization of storage carbohydrate during dormancy and in subsequent growing periods, is necessary to evaluate the impact on ecosystem metabolism due to climatic fluctuation as well as ecosystem manipulation. Analysis of the distribution of ^{14}C in *Liriodendron tulipifera* (introduced as stem inoculum of ^{14}C-sucrose) in September is being used to determine: (1) carbon turnover through respiration and root sloughing during dormancy and (2) the proportion of storage carbon utilized for growth the following growing season.

The proportion of ^{14}C utilized during the September–June period was large; only 18.5% (sum of all tree components) of labeled carbon introduced as sucrose was recovered nine months after inoculation (Fig. 3.3). Assuming random mixing and interconversion of the carbon during this period, photosynthate turnover time in *Liriodendron* trees approximates one year (1.09 per year). The amount of storage carbon incorporated in current growth was small, with 1.5% of the initial

14. P. W. Lommen et al., "A Model Describing Photosynthesis in Terms of Gas Diffusion and Enzyme Kinetics," *Planta* 98, 195–220 (1971).

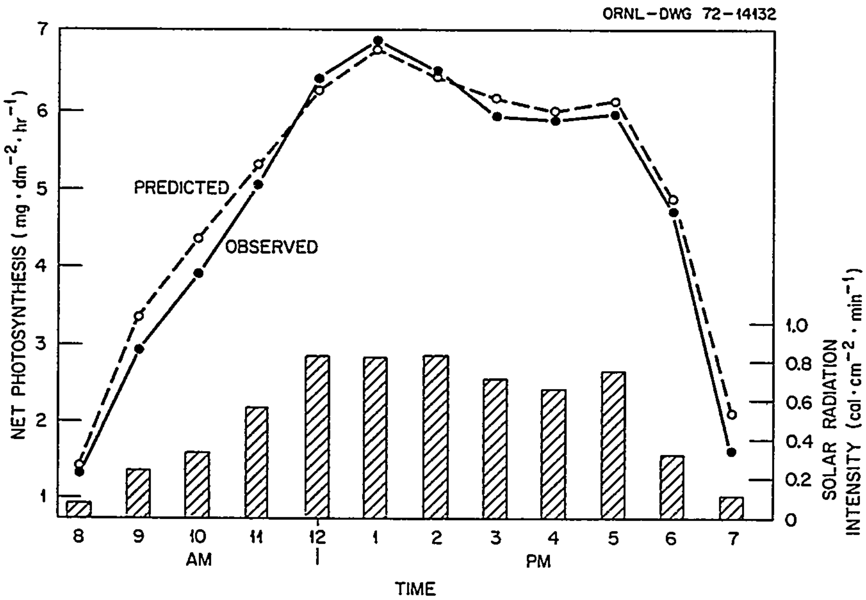

Fig. 3.2. Comparison of observed and predicted net photosynthesis for in situ yellow poplar (*Liriodendron tulipifera*) as compared with solar radiation intensities for the period 8:00 AM–7:00 PM, August 19, 1971.

carbon label recovered in 1972 leaf growth. Concentrations of ^{14}C were similar among leaf generations. An additional 0.05% of the tag was incorporated in current twig growth. Bole and large root components contributed equally to carbon storage, while small roots (<2.0 cm in diameter) contained only 0.1% of the labeled carbon at harvest. The lower ^{14}C content of small roots may reflect the fivefold difference between lateral root compartment turnover (0.21 per year) and that of storage carbon (1.09 per year).

Sequential measurements of ^{14}C distribution through time (September–June) are being used to develop the model outlined in Fig. 3.1, which will be used to simulate storage carbon turnover. A series of trees tagged with ^{14}C-sucrose this fall (*Liriodendron tulipifera, Quercus velutina,* and *Pinus echinata*) are being monitored to determine variation of rates of storage carbon transfer and interconversion among physiologically dissimilar species.

TURNOVER OF ORGANIC DETRITUS

Decomposition of Forest Floor Litter

Rates of carbon dioxide (CO_2) evolution from the forest floor reflect both the energy and weight loss from dead organic matter as it is catabolized by decomposers, primarily bacteria and fungi. Additional CO_2 is released from living roots and indicates the amount of energy necessary for maintenance, growth, and reproduction of the root tissues. Abiotic variables which affect forest floor respiration rates include temperature, moisture, pH, and available substrate. It should be possible to develop equations which predict CO_2 evolution rates, given enough information about changes in these variables and how they affect respiration. The synergistic effects of some of the variables and the fact that some variables (such as moisture) are limiting only above or below certain optimal levels make this a complex problem, especially for field situations.

Continuous measurements of CO_2 evolution from partitioned and unpartitioned horizons of the forest floor were taken for 24-hr periods at monthly (sometimes biweekly) intervals from March 1971 to March 1972 in a natural sinkhole area of a mixed mesophytic forest.[15] Moisture, available substrate, and pH did not appear to be limiting during most seasons of the year in our field plots. Small changes in temperature did affect forest floor respiration rates throughout the year. Better correlations existed between litter temperature and CO_2 evolution than between air or soil temperatures and CO_2 evolution. Thus changes in litter temper-

15. N. T. Edwards and P. Sollins, *Ecology* (in press).

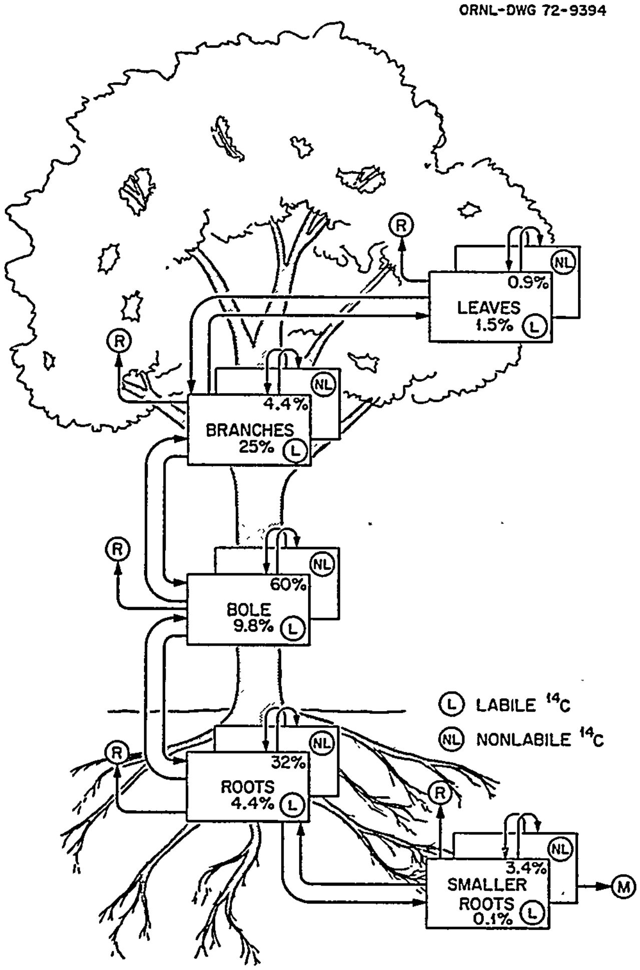

Fig. 3.3. Summary of ^{14}C distribution for a *Liriodendron tulipifera* tree (25.1 kg total tree dry weight) at the time of harvest (June 11, 1972). The tree was tagged with 3 mCi of ^{14}C-sucrose on September 22, 1971. Values in upper right corners are percent dry weight, and those below compartment labels are percent of initial tag remaining. The model under development considers labile (ethanol-soluble) and nonlabile carbon moieties and interconversions, compartment transfers, and process rates. P_N = not photosynthesis, R = respiration, and M = mortality.

ature were used to predict rates of CO_2 evolution from the forest floor.

Total forest floor respiration:

$$y = 2369 + 264x + 28.8x^2 \qquad (r^2 = 0.85). \quad (7)$$

Litter respiration:

$$y = 560 + 153x + 12.97x^2 \qquad (r^2 = 0.87). \quad (8)$$

Soil respiration:

$$y = 938 + 153x + 17.4x^2 \qquad (r^2 = 0.90), \quad (9)$$

where y = milligrams of CO_2 per square meter per day and x = temperature (°C).

Seasonal patterns of measured and predicted rates of CO_2 evolution (Fig. 3.4) indicate that for most periods of the year, litter temperature can be used to make reasonably accurate predictions of decomposer respiration rates. Good correlations were found between predicted and measured rates of CO_2 evolution: r^2 = 0.93 for forest floor respiration, r^2 = 0.88 for litter respiration, and r^2 = 0.83 for soil respiration. One utility in comparing predicted values with measured values is in the identification of the seasons when factors besides temperature become important as controlling variables. Measured rates are significantly higher than predicted rates during the fall, reflecting substrate enrichment and possibly an incubating effect of the newly fallen leaves on the soil and previous years' litter.

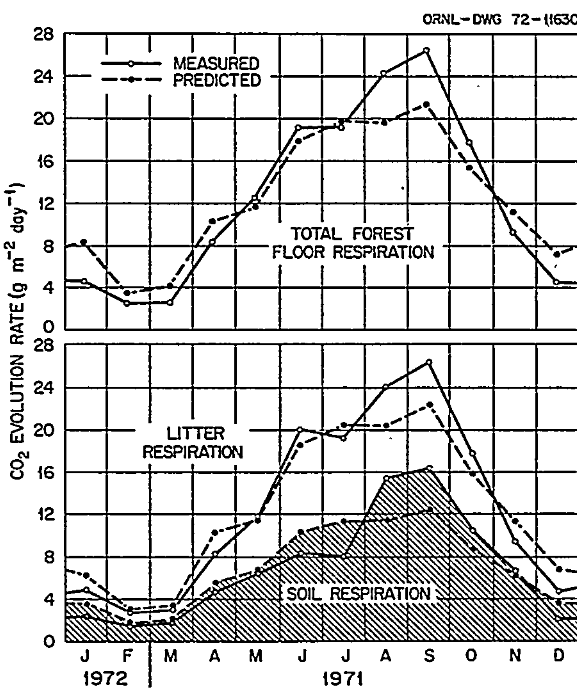

Fig. 3.4. Carbon dioxide evolution rates from the *Liriodendron* forest floor (top graph) and from partitioned horizons of the forest floor (bottom graph). Each measured value represents a daily mean calculated from two 24-hr measurements with an infrared gas analyzer. Predicted rates were calculated from mean daily litter temperatures for the days CO_2 measurements were made.

The fall overestimate and the slight underestimate during winter and spring balance out when annual totals are calculated. Annual total CO_2 evolution from the forest floor, estimated by calculating monthly means from measured values, was 4635 g/m^2 from measured values, compared with 2024 g/m^2 from predicted values. Soil respiration according to measured rates was 2527 g of CO_2 per square meter per year, compared with the predicted rate of 2525 g m^{-2} year^{-1}.

Decomposer Biota

The productivity of forest ecosystems is often limited by the rates at which nutrient elements are recycled within the system. While the bacteria and fungi are the organisms primarily responsible for decomposition and subsequent release of minerals from detritus, invertebrate consumers of the microflora largely regulate the rate at which the decomposition process occurs. Only about 10% of the decomposer animals feed directly upon leaf litter (Table 3.1), and these consume less than 1% of annual litter production. Fungus-feeding invertebrates, which comprise slightly more than 60% of the total numbers and biomass, are the dominant trophic group. Fungivores may consume up to 90 g/m^2 of fungus annually. If prevented from senescing, this quantity of fungus alone could be sufficient to account for decomposition of the total annual input of litter to the forest floor. While an important role of litter feeders and fungivores appears to be production of a fecal substrate for microfloral colonization, the fungivores especially serve as regulators which tend to maintain logarithmic growth phases of microflora. Thus litter decomposition and nutrient release tend to be gradual processes more amenable to subsequent uptake and recycling of nutrient elements by vegetation.

The implementation of the adenosine triphosphate (ATP) assay in terrestrial decomposition studies has resulted in more accurate estimates of microbial metabolic activities than had been possible previously. The relative constancy of the ATP concentration to biomass (dry weight) proportionality in microbial systems allows calculation of microbial standing crop through time from ATP concentration data. Microbial ATP concentrations, in increasing order, were: bacteria ($\bar{x}$ = 0.001 g/g) < fungi ($\bar{x}$ = 0.0022 g/g), actinomycetes ($\bar{x}$ = 0.0023 g/g) < algae ($\bar{x}$ = 0.0035 g/g). Proportionalities of ATP to several nutrients (C, N, S, P, Mg, Na, K, and Ca) for bacteria and for fungi have been established from literature and empirical data. Although calcium and potassium were included in these proportionalities, their concentrations in microbes are much more variable than other nutrient concentrations. Both biomass and nutrient ATP concentration proportionalities must be weighted by the microfloral community structure (percent bacteria vs percent fungi in litter layers and soil). Using nutrient proportionalities and microbial biomass estimates, microbial nutrient pools through time were estimated in litter layers and in soil. Coupling these estimates with microbial turnover rates in litter layers and soil through time, nutrient turnover rates have been estimated. Calorific pools and turnover rates were estimated from microbial biomass estimates and laboratory-determined microbial calorific equivalence. Using microbial biomass estimates and laboratory-determined microbial CO_2 evolution rates and Q_{10} values, contributions of microflora to total forest floor CO_2 evolution rates were evaluated through the year.[16]

The ATP assay has also been applied to the determination of metabolic activities of roots and their associated rhizosphere microflora. An ATP concentration to biomass constant has been found in roots, with roots <0.5 cm in diameter averaging ten times the ATP concentration of roots >0.5 cm in diameter. Rhizosphere biomass and rhizosphere community structure are functions of root metabolic activity (and therefore root diameter) and temperature. Nutrient pools and CO_2 evolution rate contributions of roots and rhizosphere microflora have been estimated[17] (Fig. 3.5).

Bioenergetics data are being used in predictive models which allow ATP concentration prediction from CO_2 evolution rates or temperature measurements.[18] More

Table 3.1. Trophic level distribution of decomposer invertebrates in a mesic deciduous forest

Populations characterized by both density and biomass. Values are annual means of monthly samples

Trophic level	Density (Number/m^2)	Biomass (g/m^2)
Fungivores	58,800	5.22
Litter feeders	9,200	0.97
Detritivores	4,200	0.40
Predators	20,000	1.89

16. B. S. Ausmus, "Progress Report on Soil and Litter Microfloral Energetics Studies," US IBP EDFB Memo Report (in press) (1972).

17. B. S. Ausmus, "Energetics Studies of Two Root Size Classes and Their Rhizosphere Microfloral Communities," US IBP EDFB Memo Report (in press) (1972).

18. B. S. Ausmus and N. T. Edwards, "The Relationship between Two Microbial Metabolic Activity Indices: ATP Concentration and CO_2 Evolution Rate," US IBP EDFB Memo Report (in press) (1972).

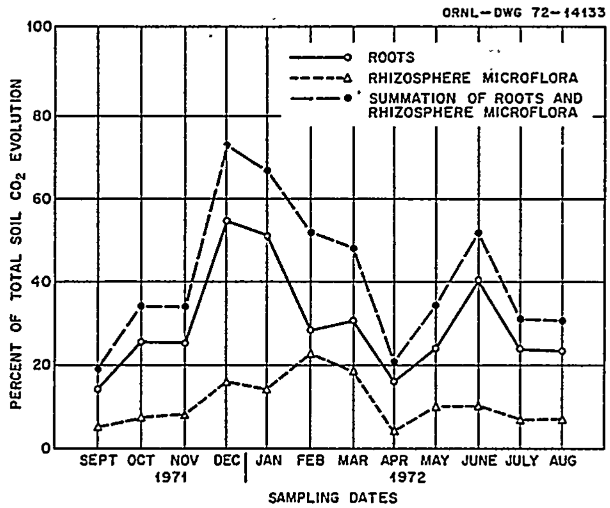

Fig. 3.5. Percent of the total soil CO_2 evolution contributed by roots and rhizosphere microflora on 12 sampling dates.

accurate prediction of ATP concentrations are possible using multiple regression models including independent variables: temperature, moisture, CO_2 evolution rates, substrate weight, C:N, C:P, C:K. A functional decomposition model is being implemented which is conceptualized on chemical form of substrate nutrients as well as substrate nutrient concentrations, substrate particle size, the mesofaunal food web, invertebrate effects on microbial substrates, nematodes, root uptake, root death and decay, and humic acid-detritus formation and decomposition.

RECYCLING OF NUTRIENT ELEMENTS

Root Death and Mineral Turnover

Studies of the chemical composition and nutrient cycles of deciduous forests primarily have dealt with aboveground material or large-diameter roots due to the recovery problems encountered in the removal of fine root materials. Roots comprise up to 32% of the total organic matter and similar proportions of the total nutrient stores. Root dieback estimates in a *Liriodendron* seedling study indicated that over 40% of the roots <0.5 cm in diameter died between November and February. This factor was applied to estimates of lateral root biomass (roots <0.5 cm in diameter) in the *Liriodendron* study area[19] assuming that 80% of the root biomass was *Liriodendron.* Total lateral root biomass was 5.8 metric tons/hectare, with a dead root pool of 2.32 metric tons/hectare.

Approximately 75% of the root mortality was contributed by fine roots (<0.1 cm in diameter). These factors were applied to the standing crop data of Harris[19] (Table 3.2). The importance of conducting biomass and mortality estimates by diameter classes is illustrated by the fact that roots <0.1 cm in diameter contain from 1.5 to 4 times greater concentrations of elements than roots >1.0 cm in diameter. Therefore, turnover estimates would be grossly inadequate if based on mineral assays for large roots. These data indicate a large turnover of inorganic elements; for example, the transfer of N, P, Ca, and K to the soil pool was 25.4, 3.8, 17.3, and 44.4 kg/hectare respectively. These should be viewed as minimum estimates, since the average dead root pool during the year was at least 20% of total standing biomass, which indicates a continuous but time-variant rate of root mortality.

Leaching and Litterfall Inputs to the Forest Floor

Mineral cycling models of forest ecosystems require accurate estimates of mineral input to the system, movement within the system, and loss from the system. The principal inputs to the system are by dryfall from the atmosphere and by atmospheric scavenging by precipitation (wetfall). Recycling within the system is very complex.

Though pathways of mineral movement have been identified, rates of movement between compartments of the system need quantification. Throughfall and stemflow leaching of some elements (such as potassium) from the canopy may account for a higher input to the forest floor than cycling by litterfall.[20]

Estimates of K, Ca, Na, P, and Mg input to the *Liriodendron* forest canopy by wetfall and dryfall and to the forest floor by throughfall and stemflow are reported. Three Wong samplers below the canopy in a 20 × 20 m plot were used to collect throughfall. One sampler above the canopy collected dryfall and wetfall. Stemflow was collected with troughs around three tulip poplar trees. Collections were made at biweekly intervals between October 1970 and October 1972. Three rainfall intensity gages were used to monitor amount and duration of rainfall during the second year.

Results of annual total input to the system for the two years are compared in Table 3.3. Ratios between K,

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19. W. F. Harris et al., "Terrestrial Primary Production," pp. 56–68 in *Ecological Sciences Div. Annu. Progr. Rep. Sept. 30, 1971*, ORNL-4759.

20. N. T. Edwards, M. H. Shanks, and G. J. Dodson, "A Study of the Water Budget and Mineral Input by Throughfall, Wetfall, Dryfall, and Stemflow in a *Liriodendron* Forest," U.S. IBP EDFB Report No. 72–45 (1971).

Table 3.2. Root mortality and nutrient turnover in a *Liriodendron* study area[a]

Element	Dead roots (kg/hectare)		Root concentration (% dry wt)		Root losses (kg/hectare)		
	0.5–0.1 cm in diameter	<0.1 cm in diameter	0.5–0.1 cm in diameter	<0.1 cm in diameter	0.5–0.1 cm in diameter	<0.1 cm in diameter	Total
Na	580	1740	0.09	0.31	0.52	5.40	5.92
Mg	580	1740	0.24	0.38	1.40	6.62	8.02
K	580	1740	1.21	2.15	7.02	37.42	44.44
Ca	580	1740	0.58	0.80	3.36	13.92	17.28
P	580	1740	0.08	0.19	0.46	3.30	3.76
N	580	1740	0.83	1.18	4.82	20.54	25.36
C	580	1740	39.00	37.00	226.20	643.80	870.00
S	580	1740	0.09	0.18	0.52	2.14	3.66

[a]Estimation of dead root pool was based on the lateral root biomass data (730 g/m^2) of Harris (1971) for roots <0.5 cm in diameter and mortality estimates of Cox (1972).

Table 3.3. Annual inputs of K, Ca, Na, Mg, and P by wetfall, throughfall, dryfall, and stemflow to a *Liriodendron* forest floor in 1971 and 1972

Totals represent sums of biweekly measurements

	Annual input (kg/hectare)									
	K		Ca		Na		Mg		P	
	1971	1972	1971	1972	1971	1972	1971	1972	1971	1972
Wetfall (precipitation)	1.95	0.72	6.09	6.05	1.88	1.81	0.70	0.70	0.04	0.06
Dryfall	2.02	2.50	4.02	4.46	0.86	1.81	0.66	1.36	0.55	0.51
Total to forest canopy	3.97	3.22	10.11	10.51	2.74	3.62	1.36	2.06	0.59	0.56
Throughfall	19.46	31.64	14.75	22.83	2.50	1.97	2.45	3.76	0.62	0.38
Stemflow	0.84	0.95	0.40	0.41	0.02	0.02	0.29	0.39	0.003	0.002
Leached from forest canopy[a]	16.33	29.37	5.04	12.73	−0.22	−1.63	1.38	2.09	0.033	−0.17
Total to forest floor[b]	20.30	32.59	15.15	23.24	2.52	1.99	2.74	4.15	0.62	0.38

[a]Obtained by subtracting the total to the canopy from throughfall plus stemflow.
[b]Obtained by adding the total to the canopy to the amount leached from the canopy.

Ca, Mg, Na, and P were: 1:0.75:0.13:0.12:0.03 for 1971. Compared with the 1972 ratios of 1:0.71:0.13:0.06:0.01, these data indicate substantial between-year consistency in the biogeochemical cycle. Greater input of sodium to the canopy by dryfall in 1972 than in 1971 and differences in amounts of canopy leaching and absorption of sodium and phosphorus resulted in the difference in the ratios. Negative sodium and phosphorus values for canopy leaching may indicate uptake of these elements by foliage and epiphytes. Total input of K, Ca, Na, and P by atmospheric scavenging and canopy leaching in 1972 compared with previous estimates of the amounts of these elements recycled by litterfall shows that canopy leaching and atmospheric scavenging account for 77% of the K, 21% of the Ca, 34% of the Na, and 9% of the P that reach the forest floor.

Seasonal patterns show highest canopy leaching rates during intense rainfalls. Input of some elements such as K, Ca, and Mg was noticeably high just prior to leaf fall, which indicates increased leaching from leaves after formation of the abscission layer. Water input to the canopy was higher (1.24×10^7 liters/ha) in 1972 than in 1971 (1.23×10^7 liters/ha), but the canopy intercepted more in 1971 (0.06×10^7 liters/ha) than in 1972 (0.05×10^7 liters/ha). In 1972 there was more precipitation and at greater intensity than in 1971. This could help explain the higher amounts of K, Ca, and Mg leached from the canopy. These data from the rainfall intensity gages should permit development of equations for predicting rates of element recycling by canopy leaching for different seasons of the year as a function of amount and duration of rainfall.

TERRESTRIAL ECOSYSTEM MODEL

Primary Production Module

A phenomenological model[21] has been developed which simulates on a daily basis the production, growth, and development of a closed-canopy homogeneous forest ecosystem. The formulation of the model is general so that it can be implemented for most terrestrial plant communities. In the initial version of the model, the vegetation is considered to be composed of overstory, understory, and herbaceous components. Each component is divided into leaves, L; bole, B; roots, R; and storage (labile or unincorporated carbohydrates), S. Bole in this context includes all aboveground biomass that is neither leaves nor labile storage.

The rate of change of the overstory leaf compartment with time is given by

$$\frac{dL}{dt} = \lambda L \left(1 - \frac{L}{aF_o}\right)\left(\frac{S}{S_1 + S}\right) \times u(L - aF_o) + L^*\delta(t - t_{pl}), \quad (10)$$

where λ and S_1 are empirical parameters, aF_o is the optimum leaf biomass, u is the unit step function, L^* is the amount of leaf material produced in initial bud break, δ is the unit *impulse function*, and t_{pl} is the physiological time at which bud break occurs. If the size of the leaf compartment exceeds the *optimum* leaf biomass, then the rate of change is given by

$$\frac{dL}{dt} = \sigma(aF_o - L), \quad (11)$$

where σ is an empirical parameter. Figure 3.6 illustrates the behavior of the overstory leaf compartment for a simulation that has been carried out for a period of a year.

Consumer Module

The consumer submodel deals with secondary production of organisms which feed on living plant and animal tissue. The energy balance of a consumer population, x_j, takes the form:

$$\dot{N}_j = \sum_i F_{ji} - \left(\sum_k F_{kj} + E_j + R_j + M_j\right), \quad (12)$$

where

$\dot{N}_j$ is the time derivative of population caloric equivalent,

F_{ji} is the feeding rate of the population on food source i,

F_{kj} is the feeding rate of the kth predator on the population,

E_j is the rate of excretory losses,

R_j is the respiration rate, and

M_j is the rate of nonpredatory mortality.

Each term in Eq. (12) is then expanded to consider linear and nonlinear interactions between the consumer and other components of the system. Rates are permitted to vary according to established or hypothesized physiological and behavioral mechanisms. The parameters of the model have been carefully selected to correspond to constants measurable by known experimental techniques. The submodel has been designed with considerable flexibility to permit implementation for a variety of consumer types. At present, the model is being modified for application to canopy insects, small mammals, fish, zooplankton, and benthic organisms. Computer implementation of the model has shown it to produce credible behavior over a wide range of environmental conditions.

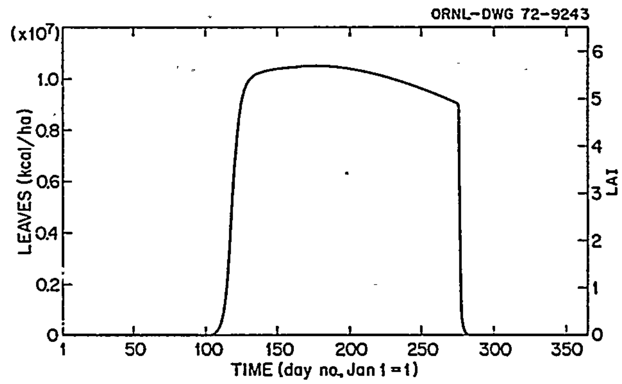

Fig. 3.6. Simulated overstory leaf biomass for homogeneous forest stand. Initial conditions and parameter values used in the simulation were based on data collected at *Liriodendron* research site and Walker Branch Watershed.

21. R. A. Goldstein, *Eastern Deciduous Forest Biome Memo Report No. 72-1.*

Decomposition Module

Terrestrial decomposition presents several difficult problems from both a modeling and an experimental design standpoint. Most active decomposition in forests is effected by the soil and litter microflora, and this process is so rapid that it cannot be expediently treated in a model which also considers longer-term phenomena such as tree growth or mammalian reproduction. The species richness and food web complexity of the soil fungi and bacteria proscribe any species-by-species attempt to model decomposition. The intent of the present submodel is to develop a paradigm someplace between the recognized complexity of natural decomposer systems and any ersatz "black-box" modeling approach.

The submodel contains three compartments representing the energy content of three nonliving energy pools. These compartments form the basis of the heterotrophic decomposition process and are

1. fresh litter,
2. old litter, and
3. soil organic compounds.

The first two compartments differ by the age and size of particles and, should the need arise, could easily be further separated based on surface-volume considerations implicit in particle size. The respiratory losses from the two litter compartments and the soil organic compartment are of the form:

$$R_i = P_i e \; 0.1(T - T_r) \log q \; X_i M_i, \; i = 1, 2, 3, \tag{13}$$

where

R_i = respiratory energy loss (kcal m^{-2} day^{-1}),

P_i = respiration rate for some ith compartment determined at some reference temperature,

T_r = reference temperature,

T = temperature,

$q = Q_{10}$ coefficient,

x_i = caloric content of compartment i (kcal/m^2),

M_i = function expressing moisture effect on soil respiration.

The M_i function is an empirically determined response surface cast on a plane with temperature and moisture axes. Most field work to this point has focused on approximating this surface with a plane (e.g., multiple and partial linear, nonlinear, and interactive components of the surface). The magnitude of the response surface indicates increased or decreased activity under different conditions.

The Q_{10} functions [Eq. (13)] implicitly mimic the behavior of microbial populations acting on various substrates, and the explicit nature of the microbial populations can be incorporated into the model if desired. In general, it is more likely that an investigator can produce a Q_{10} formulation for litter respiration than a detailed survey on the microflora and the physiological responses associated with such a survey. Hence, the model is designed to utilize the most likely data input with provisions included in the formulation to use more detailed data.

The decomposer food chain component of the model is based on the recognition of two levels of controlling parameters in trophic consideration. The first set of parameters include measurements of interest to the physiological ecologist. Such parameters might include respiration rates, feeding rates, acclimation rates determined by experimentation with individual animals. In general, these rates are concerned with movement of material, definition of input-output relations, and delineation of mass-balance considerations. The second set of parameters include those measurements generally of interest to the population ecologists (e.g., birth rates, death rates, effects of different population densities). Quite frequently, mass-balance or energetic considerations are not explicitly considered in a population model (e.g., the classic Lotka-Volterra equations), and the models are strongly oriented toward numbers of organisms.

The food chain component in the decomposer submodel uses two differential equations to represent each population or functional group. The first equation is concerned with numbers of individuals, the second with biomass. The two equations are coupled to one another by a number of expressions that usually represent a definable size (size = biomass/numbers) relationship. The general form of the equations for any single compartment in the food chain is:

$$\dot{x} = S_i B - D - \frac{x}{y} \Sigma \Phi_i, \tag{14}$$

$$\dot{y} = F_e - R_i - \frac{y}{x} D - \Sigma \Phi_i, \tag{15}$$

where

x = numbers,

y = biomass,

S_i = function which limits birth rates depending upon the mean size of an individual,

B = birth rate function,

D = death rate function,

Φ_i = predation from some ith consumer,

F_e = feeding rate function,

R_i = respiration rate function.

Water Dynamics

A phenomenological model has been developed that simulates atmosphere-plant-soil moisture relations on a daily basis. PROSPER[22] applies a water balance to a stand of vegetation, with the soil divided into several layers. A hypothetical evapotranspiration surface is defined which homogenizes the plant and soil characteristics. A combined energy-balance–aerodynamic method is used to derive an equation for evapotranspiration as a function of a resistance to vapor transfer which is characteristic of the surfaces from which evapotranspiration takes place. This resistance is a function of the water potential of the surface. This is analogous to the relationship between stomatal resistance and leaf water potential. A mass balance is applied to the water flowing through soil and plant. The flow of water within and between soil and plant is a function of soil conductivity, soil water potential, root characteristics for each soil level, and surface water potential. Soil conductivity and soil water potential are functions of volumetric soil water content. By setting water flow to the evapotranspiration surface equal to vapor flow away from the surface, surface water potential, surface resistance to vapor transfer, evaporation from the litter surface, and transpiration through the plant can be calculated. PROSPER also traces daily volumetric water content of the different soil layers and predicts runoff. Figure 3.7 illustrates the simulated daily evapotranspiration for Walker Branch Watershed for 1969 using local meteorological data.

22. R. A. Goldstein and J. B. Mankin, "PROSPER: A Model of Atmospheric-Soil-Plant Water Flow," pp. 1176–81 in *Proceedings of the 1972 Summer Computer Simulation Conference, June 14–16, 1972, San Diego, California*, 1972.

Carbon Pools and Fluxes in a Forest Ecosystem

Fundamental to the analysis of energy flow through ecosystems is an understanding of the functional relationships between photosynthesis, respiration, and productivity of the system (Fig. 3.8). Relationships between pools and fluxes, seasonality, and variability of carbon need to be explored by comparison of data from different ecosystems to elucidate patterns of carbon dynamics in terrestrial ecosystems.

The most comprehensively analyzed ecosystem to contrast with our *Liriodendron* forest is the more xeric oak-pine forest at Brookhaven (Table 3.4). The mesic Oak Ridge forest has a total standing crop of 8.66 kg of carbon per square meter and a net primary production (NPP) of 685 g of carbon per square meter per year, while the respective values for the oak-pine forest can be calculated from biomass and estimated carbon content to be 5.96 kg of carbon per square meter and 598 g of carbon per square meter per year. Relative

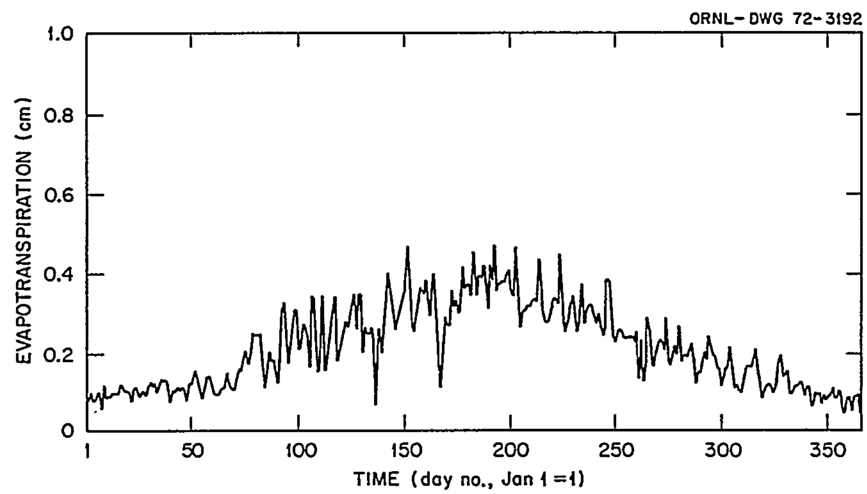

Fig. 3.7. Simulated daily evapotranspiration for Walker Branch Watershed for 1969 using PROSPER. Source meteorological data provided by Atmospheric Turbulence Diffusion Laboratory, Oak Ridge.

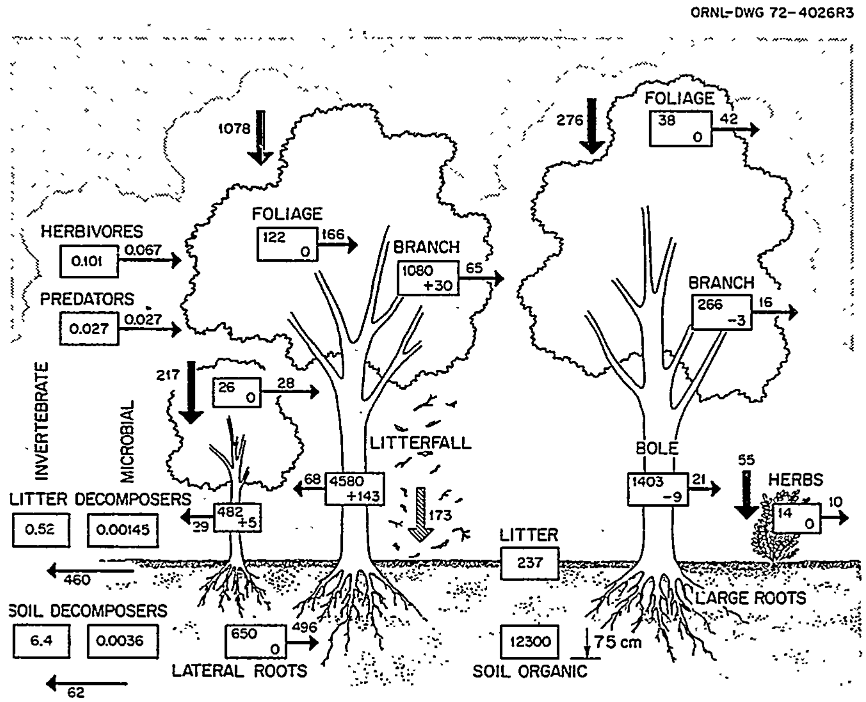

Fig. 3.8. Carbon cycle in the *Liriodendron* forest at ORNL. Structural components of the ecosystem have been abstracted as compartments. Values in upper left of boxes are standing crop; values in lower right are annual increment. From left to right, trees represent understory, dominant *Liriodendron,* and other canopy species. Major fluxes through the system are illustrated by arrows (horizontal for respiratory losses and vertical for photosynthetic fixation). Units of measure are grams of carbon per square meter for standing crop and grams of carbon per square meter per year for annual increments and fluxes.

Table 3.4. Comparative carbon metabolism of two forested ecosystems – a mesic deciduous *Liriodendron* forest (Reichle et al., 1972) at Oak Ridge National Laboratory and a xeric mixed *Quercus-Pinus* forest (Woodwell and Botkin, 1970) at Brookhaven National Laboratory

Parameter	*Liriodendron* forest	*Quercus-Pinus* forest
Total standing crop (TSC)	8.66[a]	5.96[a]
Net primary production (NPP)	0.68[b]	0.60[b]
Relative production (NPP/TSC)	8%	10%
Autotroph Respiration (R_A)	0.94[b]	0.68[b]
Maintenance efficiency (R_A/TSC)	0.11	0.11
Heterotroph respiration (R_H)	0.52[b]	0.37[b]
Ecosystem respiration ($R_E - R_A + R_H$)	1.47[b]	1.01[b]
Net ecosystem production (NEP = NPP $- R_H$)	0.16[b]	0.28[b]
Annual decay	0.52[b]	0.36[b]

[a]Kilograms of carbon per square meter.
[b]Kilograms of carbon per square meter per year.

productivity, the ratio of NPP to standing crop, is higher in the oak-pine forest (10%) than in the tulip poplar forest (8%). Autotrophic respiration (R_A) by the oak-pine forest is lower at 675 g of carbon per square meter per year than the tulip poplar forest at 941 g of carbon per square meter per year, and the respective ratios of R_A to standing crop are identical at 0.11. Gross primary production (GPP) by the Oak Ridge forest was 1.63 kg of carbon per square meter per year, compared with 1.36 kg for the Brookhaven forest, although the respective ratios of NPP to GPP were essentially identical at 0.42 and 0.45.

Estimates of net ecosystem production (NEP) for the two forest ecosystems were substantially different (Table 3.4). NEP for the oak-pine forest was between 271 and 294 g of carbon per square meter per year (depending on whether allometric or gas exchange values were used to make the calculation), while NEP for the *Liriodendron* forest was 161 g of carbon per square meter per year. Although the tulip poplar forest had higher GPP and NPP, its higher total ecosystem respiration (R_E) of 1.47 kg of carbon per square meter per year (compared with 1.01 kg for the oak-pine forest) resulted in a lower NEP. The higher relative respiration of the *Liriodendron* forest (R_E/NEP of 9.1, compared with approximately 3.6 for the oak-pine forest) reflects several fundamental differences between internal components of the two ecosystems.

The distribution of standing crop between above- and belowground components of the two forests varies severalfold (Fig. 3.8). While the oak-pine forest, with a standing crop of 5.96 kg of carbon per square meter, has an above- and belowground ratio of 1.8, the tulip poplar forest has a ratio of 4.2 for its biomass of 8.66 kg of carbon per square meter. Heterotrophic respiration (R_H) in the mesic Oak Ridge forest (524 g of carbon per square meter per year) was nearly twice that of the more xeric forest at Brookhaven. This discrepancy was due to the apportionment of R_E between R_A and R_H; the ratio of R_A/R_H for the oak-pine forest was 2.5 but only 1.8 in the tulip poplar forest.

While the tulip poplar forest annually loses 522 g of carbon per square meter through decay, the oak-pine forest turns over only 360 g. For the mesic deciduous forest, decay amounts to an annual turnover of 4.1% of the detritus carbon pool of 12.85 kg of carbon per square meter. Approximately 60% of the total carbon in the tulip poplar forest (21.51 kg of carbon per square meter) is in the detritus pool (Fig. 3.8). With an estimated NEP of 161 g of carbon per square meter per year and an annual woody increment of 168 g of carbon per square meter, the carbon pool in litter and soil detritus remains in equilibrium according to our initial conditions. The oak-pine ecosystem has a high NEP to standing crop ratio of 0.05, vs 0.02 for the tulip poplar forest, reflecting increasing carbon pools in both standing crop and soil organic matter. The sources and rates of carbon accumulation in soil are multiple. In the *Liriodendron* forest, annual decomposition respiratory losses account for 522 g of carbon per square meter; 228 g of carbon per square meter per year from litterfall, dead bole and frass inputs is less than the additional 294 g root death required to keep the detritus carbon pool in equilibrium.

Residence times of carbon in components of forest ecosystems vary considerably, depending upon input and output fluxes as well as pool sizes. Some components, such as foliage, have a turnover time of one year or less, while others, such as small roots, may have a surprisingly rapid turnover rate (350 g of carbon per square meter per year/1670 g of carbon per square meter per year, or a residence time of approximately five years). Rapidly decomposable components of fresh litterfall may have residence times of only 0.5 year, while the turnover rate of soil organic matter in the tulip poplar forest (0.0048 per year) is equivalent to a turnover time of approximately 200 years. Turnover of carbon through the mortality of woody components of trees (50 g of carbon per square meter per year/6990 g of carbon per square meter = 0.0071 per year) is equally slow and yields a residence time for carbon in this ecosystem component of nearly 140 years. Overall mean residence time for carbon in the tulip poplar forest was 15 years (1456 g m^{-2} $year^{-1}$/21,510 g/m^2 = 0.068 per year) calculated from the ratio of R_E to total ecosystem carbon pool. How these individual and collective turnover rates for carbon are affected by seasonal phenomena and how they vary among ecosystems of different type and age are questions which yet need to be answered before we can accurately describe the dynamics of carbon in terrestrial ecosystems in detail.

4. Program Applications

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The objectives of the Ecosystem Analysis Program are such that they encourage application of basic research to solution of applied problems. Research studies exploring the regulating mechanisms of ecological processes provide insight into the internal dynamics and controls of complex systems. As ecosystem models become more refined, their utility increases for simulating system behavior as well as providing early identification of key variables, parameters, and linkages among subcomponents. The ramifications of unanticipated stresses upon ecosystems or conversely the engineering of ecological systems to improve environmental quality are continuing challenges to the ecologist. Scientific inquisitiveness into unresolved questions and application of existing capabilities to newly recognized problems provide for both the relevance of ongoing research and the basis for new research emphases within the Division. This year the staff have been particularly responsive to environmental impact assessment related to nuclear and nonnuclear energy technologies and have become involved in a number of exploratory efforts with other laboratory divisions.

COLUMNAR DENITRIFICATION STUDIES

The high nitrate nitrogen content in some of the industrial waste effluents from the Y-12 area prompted us to investigate the possibility of converting the nitrate to the elemental gaseous form via biological denitrification. Denitrification is often called "dissimilatory nitrate reduction," in contrast to conventional "assimilatory reduction," where reduction to the ammonium form for protein synthesis occurs. Under anaerobic conditions the nitrate ion serves as a terminal hydrogen acceptor, rather than oxygen in an aerobic environment, in microbial metabolism. Nitrate nitrogen in the presence of glucose is converted to elemental gaseous nitrogen by the facultative microbe *Pseudomonas denitrificans* in the following manner:

$$5C_6H_{12}O_6 + 24NO_3^- \rightarrow 30CO_2 + 18H_2O + 24OH^- + 12N_2 \; .$$

An experimental denitrification column was developed to process unsaturated flow of waste effluent through a soil-sand mixture. An experiment showed that 8 liters of Y-12 effluent containing 2400 ppm nitrate nitrogen (approx 12,000 ppm NO_3) recycled under anaerobic conditions through the soil-sand column (9.5 cm in diameter, 122 cm long) contained less than 50 ppm nitrate nitrogen after 72 hr. Methanol was used as a carbon-hydrogen source in a ratio of 2.75 g to each gram of nitrate. Monitoring the N_2 in the off-gas demonstrated that the denitrification rate was dependent on concentration of nitrate nitrogen within the column (Fig. 4.1). The rate of denitrification based on the disappearance of nitrogen in the effluent and N_2 off-gas production was approximately 176.5 g of nitrate nitrogen per cubic meter of column volume per hour. Extrapolation to larger columns might be premature, but at this rate a 3.04- by 3.04-m column should be able to denitrify slightly over 11,000 liters of effluent containing 2400 ppm nitrate nitrogen every 24 hr. Thus, in theory, $11.0 \times 10^{+4}$ liters of similar effluent could be stripped of its nitrate nitrogen in 24 hr with ten such columns. Several-fold increase in efficiency

1. Dual capacity.
2. Consultant, Forestry Department, University of Tennessee.

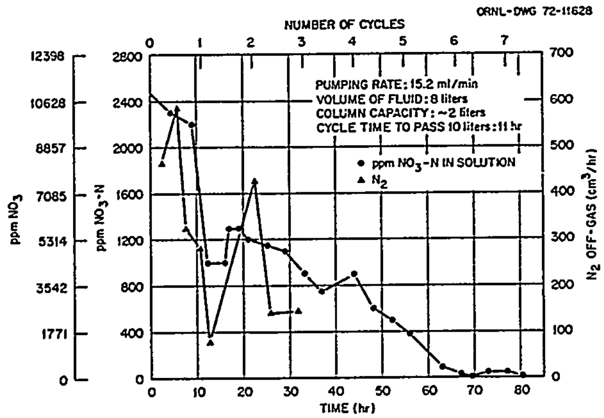

Fig. 4.1. Denitrification vs time as measured by nitrate loss and N_2 production. The low nitrate concentrations at 11–17 hr are due largely to dilution by low-nitrate solution in the column at time 0.

may be obtained by raising operating temperature to the 55–60°C range.

TERRESTRIAL DISPOSAL OF INDUSTRIAL EFFLUENTS

The feasibility of land disposal of industrial effluents containing high concentrations of nitrate is being evaluated for forested ecosystems. Land disposal of wastes capitalizes upon normal metabolism and growth of natural biota to incorporate waste material into forest mineral cycles. While superficially attractive as a means of nondegradative disposal, a serious loss of environmental quality can result from mismanagement due to lack of understanding of ecological processes governing waste incorporation.

In work initiated this year, acidic effluent was first neutralized to precipitate potentially toxic and radioactive materials. The neutralized effluent with a NO_3^- nitrogen concentration of ~2500 ppm was spray irrigated on forested areas (second growth, mixed deciduous). A series of plots was established to determine a rate of nitrate application within the incorporation capacity of the forest ecosystem but sufficiently high to minimize the capital costs and land area required. In order to maximize the residence time of highly soluble nitrate in the biologically active litter and soil zones, irrigation coincided with temporary summer droughts during which free soil water was minimal.

The efficiency of land disposal of nitrate is being evaluated by monitoring the NO_3 nitrogen lost from the system in percolating soil water. The overall disposal efficiency must be evaluated over a period of saturated soil conditions when readily leached materials such as nitrate will be lost from the soil system. Free soil water availability during the course of the study has been sporadic as anticipated. Nitrate concentrations (0.04 to 0.76 ppm) in the samples available from irrigated areas were within or slightly higher than the range of comparable values from control areas (0.04 to 0.14 ppm nitrate nitrogen). Nitrate concentrations in soil solution were independent of treatments of 0, 55, 137, and 220 kg of nitrate nitrogen per hectare. Total nitrogen and ammonium nitrogen were not different from control values.

One immediate effect of nitrate irrigation is an accelerated rate of decay of forest litter (Fig. 4.2). The increased turnover of organic matter places severe restrictions on the maximum rate of application and length of time a forested area can be used for disposal. The decay of O_1 material was not affected by addition of nitrate salts, while both pools of O_2 and twig-branch material were depleted. The decay patterns suggest that with application rates greater than 220 kg of nitrate nitrogen per hectare, the efficiency of assimilatory denitrification would decrease due to (1) entire removal of twig-branch substrate and (2) the apparent limited capacity of O_2 microflora to further nitrate assimilation because of other undefined limiting factors to micro-

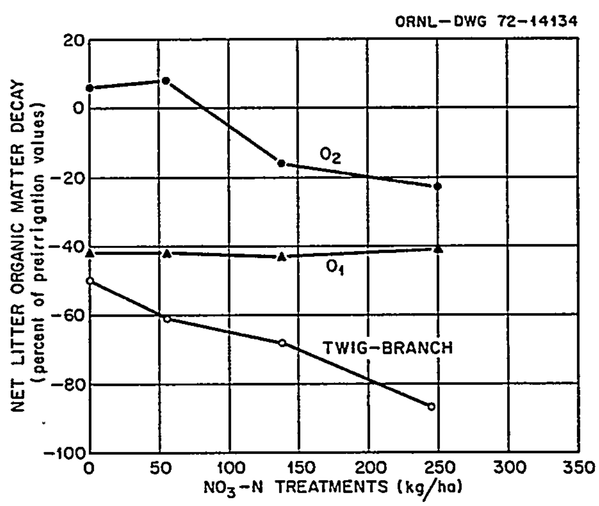

Fig. 4.2. Decay of forest floor components following spray irrigation of nitrate salts. Values are percent change of O_1 (corrected for direct addition of salts), O_2, and twig-branch material from conditions prior to irrigation (June 6, 1972). Irrigation was performed incrementally commencing on June 27, with the final application on August 24. Litter collections summarized here were made on September 11 (18 days following final irrigation). Therefore, the responses summarized should be viewed as transitory and subject to further measurement in June 1973.

flora metabolism. The decay response of twig-branch material indicates that capacity for nitrate disposal could be increased through utilization of forest areas with large amounts of slash or fallen woody material.

SURVEY OF OZONE PRODUCTION ASSOCIATION WITH ENERGY PRODUCTION FACILITIES

The generation of electrical power both by conventional and nuclear-fueled facilities results in the production of gaseous effluents. Associated with both modes of electrical generation is the production of ozone (O_3). Ozone has been well documented as a component of the photochemical smog complex, its production being the result of light-mediated reactions of atmospheric oxygen in the presence of elevated levels of (SO_x) and (NO_x).[3] Ozone formation is also known to occur around high-voltage conductors as a result of ionization of air and water vapor particles.[4] Preliminary results of investigations by electric utilities and EPA concerning O_3 concentrations near 765- and 1500-kV transmission corridors suggest that O_3 concentration increases above ambient appear to be within the limits of instrument uncertainty (0.002 ppm, as compared with the 0.08-ppm once-per-year maximum given in 42 CFR 410).[5] This problem is being pursued in greater detail, however, as O_3 concentrations of 5 ppm have been reported for areas in West Virginia where no known O_3 source exists.[6]

Analysis of O_3 concentrations directly beneath two 500-kV transmission lines on the Oak Ridge AEC

3. A. J. Haagen-Smit and M. M. Fox, "Ozone Formation in Photochemical Oxidation of Organic Substances," *Ind. Eng. Chem.* 48, 1484–87 (1956).

4. J. Zaborsky and J. W. Rittenhouse, *Electric Power Transmission*, chap. 4, The Ronald Press, New York, 1954.

5. Environmental Protection Agency, *National Primary and Secondary Ambient Air Quality Standards*, part 410, chap. IV, 1971.

6. "Determination or Coronal Ozone Production by High Voltage Electrical Transmission Lines," Procurement Plan, EPA, Research Triangle Park, N.C.

Table 4.1. Site locations and measured ozone concentrations

Values determined by a model 612 ozone detector manufactured by REM, Inc., 2000 Colorado Ave., Santa Monica, Calif. 90404

Date	Time	Location	Ozone concentration (ppm)
4-6-72	0900	ORNL (background)	0.020
	0930	Edge of two 500-kV transmission line right-of-way (Oak Ridge AEC reservation)	0.210
	0940	Center of two 500-kV transmission line right-of-way (Oak Ridge AEC reservation)	0.230
6-4-72	1000	ORNL (background)	0.012
	1145	Melton Hill Dam	0.043
	1305	Edge of two 500-kV transmission line right-of-way (Oak Ridge AEC reservation)	0.022
	1315	Center of two 500-kV transmission line right-of-way (Oak Ridge AEC reservation)	0.025
6-15-72	1230	ORNL (background)	0.022
	1030	Center of two 500-kV transmission line right-of-way (Oak Ridge AEC reservation)	0.027–0.034
	1500	Bull Run Steam Plant, Claxton, Tenn.	
		300 yd from substation	0.042–0.045
		Ca. 1 mile downwind from steam plant	0.025
5-16-72	1205	Foothills Parkway pulloff (Smoky Mountains south of Knoxville, Tenn.)	0.043
	1300	Lookrock parking area (Smoky Mountains south of Knoxville, Tenn.)	0.050
	1340	Chilhowee Reservoir (near dam)	0.058–0.061
	1520	Near Alcoa aluminum plant (Maryville, Tenn.)	0.050

reservation April 6, 1972, revealed O_3 concentrations ranging from 0.18 to 0.21 ppm, compared with the 0.08-ppm once-per-year maximum allowable under 42 CFR 410 (Table 4.1). Subsequent analyses at the same location yielded O_3 concentrations ranging from 0.02 to 0.03 ppm, suggesting that the extremely high concentrations reported on April 6 may have been due to a moderate temperature inversion. Analyses carried out during a 4-hr period May 16, 1972, showed O_3 concentrations ranging from 0.04 to 0.06 ppm over a series of sites from Knoxville, Tennessee, extending into the foothills of the Great Smoky Mountains.

While a more elaborate experimental design is required to establish correlations between O_3 concentrations, site location, meteorological conditions, possible sources, etc., it is significant that the concentrations measured approached maximum air quality standards and exceeded levels known to cause damage in sensitive plant species (i.e., 0.03 ppm).[7] Occurrence of elevated O_3 concentrations, coupled with knowledge of the synergistic effects of O_3 with SO_2 and other oxidants, suggests that further investigations are warranted toward determination of the magnitude and frequency of occurrence of elevated levels of O_3 and associated atmospheric pollutants and their effects upon natural vegetation. This conclusion is further supported by topographic features of the Southeast, characterized by mountain ridges of Kentucky, North Carolina, Tennessee, and Virginia, which aid in trapping and holding atmospheric pollutants, thus allowing for maximization of vegetational as well as human exposures.

ENVIRONMENTAL EFFECTS OF COOLING TOWER DRIFT

Potentially detrimental long-term environmental effects of cooling towers have been questioned in connection with nuclear-powered steam generating plants. The concern arises from the use of toxic substances as biocides (organozinc phosphate) and for corrosion control (chromate) in cooling tower water which is subject to uncontrolled loss to the environment through aerosols or through blowdown into surface waters. A preliminary assessment of chromium content in forest and grass vegetation is in progress in the vicinity of cooling towers at the Oak Ridge Gaseous Diffusion Plant (ORGDP). The towers have been in operation approximately 25 years, with continuous use of chromates to condition the cooling waters.

A preliminary inventory has been made of chromium and zinc concentrations in several plant species. The areas sampled represent different ecological communities (grasslands, old fields, forests) which have been exposed to drift in the vicinity of the ORGDP cooling towers. Sampling stations varied from 15 to approximately 1370 m from the towers along the axis of predominant northeasterly winds. Vegetation samples included grasses, forbs, and trees. As expected, concentrations of chromium and zinc in vegetation appear to decrease with increasing distance from the cooling towers. Maximum concentration of chromium (325 μg per gram of plant material) was observed 15 m from the tower and decreased to 10 μg/g at 1370 m. Concentrations of zinc ranged from 67 μg per gram of plant material to 28 μg/g at 15 and 1370 m respectively. Although firm conclusions would be premature, these preliminary data indicate chemical transport in drift. Concentrations observed in plant parts were at least an order of magnitude greater than typical background values reported for 25 botanical families.[8] These values are preliminary and do not differentiate between natural chromium or zinc and chromium or zinc deposited from cooling tower drift. Control areas presently are being sampled to provide base-line chromium and zinc concentrations for comparison with data collected from vegetation growing near the cooling towers. Further studies will focus on concentration magnitudes, distribution on the landscape, comparison with regional backgrounds, and potential effects on biotic components of ecosystems.

IBP WOODLANDS WORKSHOP

As a part of the International Biological Program, a joint ecological effort by 57 countries, more than 50 ecologists from 17 countries shared information on the world's forests during a unique workshop hosted by the Environmental Sciences Division August 13–26, 1972. Scientists from Europe, Asia, and Australia contributed data on tropical, subtropical, evergreen, and deciduous forests. Working with the staff of Environmental Sciences, Mathematics, and Instrumentation and Controls Divisions and collaborating IBP university scientists, they constructed simulation models of productivity and mineral cycling for these systems.

The objectives of the workshop were to initiate data summaries for primary production and mineral cycling

7. A. C. Costonis and W. A. Sinclair, "Relationships of Atmospheric Ozone to Needle Blight of Eastern White Pine," *Phytopathology* 59, 1566–74 (1969).

8. G. K. Davis, "Chromium in Soils, Plants and Animals," *Chromium*, vol. I, ed. M. J. Udy, ACS Monograph Series No. 132, pp. 105–9.

in forest ecosystems and to develop ecosystem models for budgets and dynamic behavior of carbon and selected elements. Special work groups concentrated on interpretation and comparison of ecosystem analyses for both total forest systems and their component parts. Special work groups concentrated on interpretation and comparison of ecosystem data on a global scale. Previously prepared summaries of national woodlands research projects were compiled for a directory of IBP/PT programs. Active involvement of all participants in data synthesis, modeling, and interpretation, as well as mutual exchange of ideas, provided valuable background for initial stages of international IBP woodlands synthesis.

Specific accomplishments consisted of the filing of 30 documented data sets on ecosystem production, mineral cycling, and hydrologic cycles representing 18 different woodland research sites in 14 countries. In addition to these standardized data sets, key word abstracts, listings of data set parameters, and written text describing each project were prepared. Each data set was inputted, using a standardized data format, to a linear, constant-coefficient simulation model. Four nonlinear seasonal simulation models were developed for a generalized deciduous, boreal coniferous, tropical deciduous, and broadleaved evergreen forest using parameters and functions derived from appropriate data sets. Preliminary comparison of model results and matrices of numeric data were prepared for second-order analysis and interpretation across all woodland sites represented. Detailed results of the meeting will be available in a published proceedings of the workshop.

5. Eastern Deciduous Forest Biome, U.S. International Biological Program

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The Eastern Deciduous Forest Biome is a major research effort within the U.S. International Biological Program (IBP). The Environmental Sciences Division of Oak Ridge National Laboratory manages and coordinates this large scientific program, which integrates many investigators and institutions in the eastern U.S. Research into various ecosystem processes is coordinated across the biome region at five major sites: one terrestrial (Triangle, North Carolina), two aquatic (Lake George, New York, and Lake Wingra, Wisconsin), and two terrestrial and land/water interaction sites (Coweeta, North Carolina, and Oak Ridge, Tennessee). The Biome is involved in sophisticated research into primary and secondary biotic production, decomposition, mineral cycling, and abiotic environmental parameters.

A large mathematical modeling component, a Biome Information Center, and a Biome and Regional Analysis program, focusing on entire landscapes where the spatial mix of ecosystem types and the transformation of an area, through time, from one type to another, are important program elements in the Environmental Sciences Division.

Three generalized Biome objectives can be simply stated as (1) an understanding of the interaction of structure and function in ecosystems in the Eastern Biome region, (2) an application of this knowledge toward the solutions to a number of pressing environmental problems, and (3) development of integrated research teams with the capabilities, initiatives, and incentives to attack and solve environmental problems with maximum efficiency.

MANAGEMENT

Program direction is accomplished through the Biome Executive Committee, which met six times during the past year (once in Cincinnati, once in Washington, D.C., and four times at Oak Ridge National Laboratory). Problems addressed included those of continued funding for the program, research direction, data management, and more recently, as IBP moves into Phase III – Synthesis, needs and mechanisms for synthesis of the large amounts of ecological information emanating from the total program.

In February, the First Annual Information Meeting was held at the University of Georgia. This was attended by 187 scientists, including representatives from a number of other US-IBP programs. The three-day meeting, consisting of plenary and process research sessions, was highlighted by the presentation of 111 research papers covering all aspects of the Biome program.

Twenty-four papers in three major sessions were presented by Biome scientists at the 25th Annual Meeting of the American Institute of Biological Sciences (AIBS), held at the University of Minnesota in

1. Instrumentation and Controls Division.
2. U.S. Forest Service.
3. Presidential Intern.
4. Mathematics Division.

August. The papers addressed problems in terrestrial and aquatic ecosystem ecology, land/water interaction, land use and environmental impact, and systems analysis and modeling in ecology.

An International Woodlands Workshop was sponsored by the Biome from August 13 to 26, 1972, and was attended by over 50 ecologists representing 17 countries. Preliminary syntheses of various data sets were accomplished, and four nonlinear seasonal simulation models were developed for generalized deciduous, boreal coniferous, tropical deciduous, and broad-leaved evergreen forests. This Workshop was immediately preceeding the Vth General Assembly of the International Biological Program at the University of Washington, Seattle. Participation in the Assembly included organization of and presentation of papers in major symposia, preparation and coordination of a Biome display portraying the program for the benefit of foreign delegates, and a number of key roles on various panels and committees. The aim of the final Assembly was to steer IBP through the synthesis phase (1972–74) and to prepare for a transition of research activities to another framework in the post-IBP period.

BIOME AND REGIONAL ANALYSIS

The program is committed to a study of ecological phenomena at scales ranging from areas larger than the sites (county, USFS Survey Units) to the entire biome. Most of the effort involves a consideration of the association of species and how the patterns of association change from region to region, primary productivity of entire landscape units as influenced by environmental variables, and forest succession research examining both natural and man-induced changes in the regional mixture of forest types.

Forests in the Biome vary in species composition, population structure, and many other features. Classification is one approach to analysis of such variability, and several classifications and vegetation maps of the Biome are available. An alternative considers species composition and population structure as potentially continuous variables. This approach diminishes problems associated with intraclass heterogeneity and eliminates the necessity of developing different models for the dynamics of each of a series of distinct forest vegetation types. At present, multivariate statistical methods are being developed to provide a continuous analysis of landscape variability.

Using data from the Forest Service cooperative forest inventories to develop a Biome-wide ordination of forests will permit description of any forest stand in the Biome, to varying levels of detail, on the basis of geographical location and position within an ordination hyperspace. The initial objective is to provide a series of species coordinates within a multidimensional compositional hyperspace for each inventory region. Species coordinates and a variety of area samples (plots, stands, watersheds) can be related to one another in the ordination. The dimensions of the ordinations can be related to large-scale environmental gradients by multivariate regression and canonical analysis. Standing crop, primary productivity, and other local ecosystem features and rates (including succession) can be predicted on the basis of stand position within the ordination and other large-scale variables such as latitude, longitude, and elevation. This will provide means of extrapolating the results from site research to areas outside specific sites. The major sites, as well as individual stands and landscape units at other cooperating sites, will be placed within the ordination hyperspace to determine the degree of Biome coverage.

Regional productivity research began in the summer of 1971, with profile studies across North Carolina, Tennessee, Wisconsin, New York, and Massachusetts. These studies estimated productivity by land use category in an attempt to compare rates of production between land uses, as well as between regions. In these studies, clear distinctions in productivity among land use types were blurred by the ambiguities of converting extant data on commercial yields of farms and forests into estimates of net primary production. Considerable research is continuing on these conversion factors. From the standpoint of energy input, production of agricultural and forest lands cannot be adequately compared without a consideration of the amount of man's energy (e.g., fuel) entering the two systems.

Research is continuing on production in North Carolina, Wisconsin, and at Oak Ridge, refining models of productivity on a world scale, assessing the energy costs of agricultural production, including the technologic inputs, and mapping production using regressions of net primary production on evapotranspiration from a network of weather stations in the continental United States. Development of reasonable forest conversion factors and a model of the control of forest production by environment as expressed by a water budget incorporating the effects of topography on energy and moisture inputs to the plant community are continuing.

A preliminary forest succession model for Michigan was developed early in the year (Fig. 5.1). The model is composed of compartments representing forest types with compartment linkages representing flow (acres per

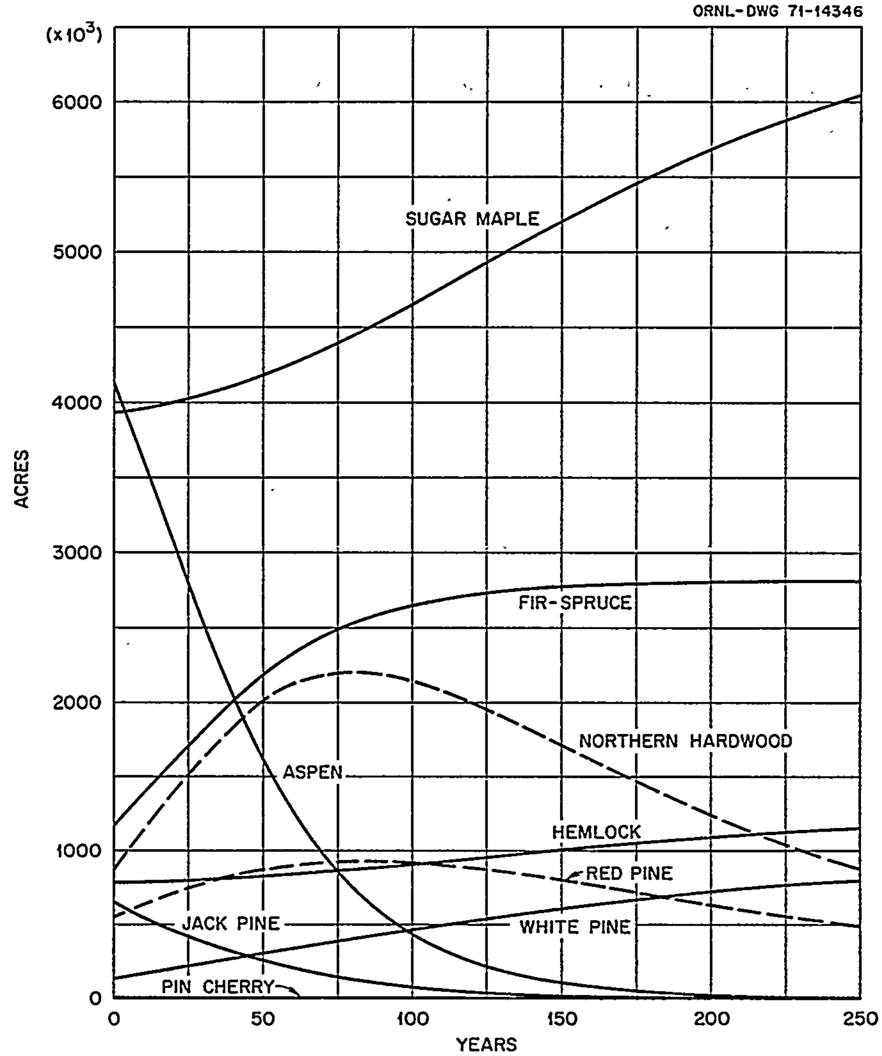

Fig. 5.1. Typical output of regional succession model. The names identifying each curve indicate dominant tree species characterizing a given forest stand type.

year) from one type to another. The original model contained no feedback (system perturbations such as fire cutting or disease) from climax to pioneer types and thus represented the latent or potential acreage fluxes for the region. The compartments, linkages, and fluxes were determined from estimates and literature values. Recently, perturbations have been added to the model rendering it more realistic as an estimator of the future acreage of forest types within the region.

Sufficient information on the successional processes is not available within all regions of the Biome. Thus it is necessary to attempt to derive models of succession based on USFS structural data taken at one point in time. Species replacement vectors (e.g., relating young and old age classes) can be approximated by size-association analysis, and the rates of transfer among compartments can be expressed as a function of species growth rates and longevity and expected mortality rates, all available from Forest Service inventory data.

Completed models reflect the intrinsic successional trends within specified regions in the Biome, and further implementation of perturbations by appropriate groups of forest and wildlife managers will result in alternative long-term projections of forest composition in the region.

ANALYSIS AND MODELING

As mathematical models find increasing application in ecology, continued effort is required to increase our understanding of their limitations. The numerous populations of organisms in an ecosystem are customarily modeled with a small number of variables. However, there is little understanding of the errors introduced by such abstraction, or of the limitations on the predictive capabilities of the model.

Consider two species of organisms performing "parallel" functions in an ecosystem. That is, both consume a resource at some constant rate, I_i, and both show some turnover rate, but the populations do not directly interact. Two species of herbivores would exemplify this relationship. If population turnover can be expressed by a rate constant, k_i, multiplied by the biomass of the population, x_i, then it should be possible to represent changes in the population as

$$dx_i/dt = I_i - k_i x_i \,. \tag{1}$$

If the slower population, that is, with the smaller value of k, is represented by $i = 1$, then we can represent k_2 as bk_1, where b has some value greater than 1. We can also express x_2 as ax_1, where a has a value greater than zero. The error introduced by combining these two populations into a single variable, x_3, can be written as

$$E(t) = x_1(t) + x_2(t) - x_3(t) \tag{2}$$

if the desired prediction involves the total biomass in this portion of the ecosystem. A generalized expression for error can be obtained by substituting the solution for Eq. (1) into Eq. (2) and integrating over the time interval of interest.

Figure 5.2 shows isopleths of error for various values of a and b. The values were generated by setting $x_1 = x_2 = x_3 = 0$ at $t = 0$ and integrating the error expression from $t = 0$ to $t = 3.5/k_1$, which represents an approach to about 97% of equilibrium. The errors can become quite large if both population size and turnover rate differ radically. If 5% error were considered an acceptable level of error, turnover rates should not differ by more than 1.3 to 1.4 times when population sizes differ significantly. As the difference in turnover rate becomes greater than one and a half times, one of the populations must become an insignificant fraction of the total biomass to avoid significant error.

A mechanistic model of an open-water lake ecosystem is being developed as a joint project of staff from Oak Ridge National Laboratory, the University of Wisconsin, and Rensselaer Polytechnic Institute. The model is designed to synthesize research results, summarize current understanding of lake ecosystems, and structure future research. The total model considers primary production, secondary production, and decomposition processes.

The primary production modules include a phytoplankton submodel and a rooted macrophyte submodel. The macrophyte submodel closely follows theoretical developments in terrestrial primary production and simulates seasonal fluctuations in photosynthesis, plant growth, and storage of photosynthates.

Secondary production modules include zooplankton production and fish growth. The zooplankton module is designed to test hypotheses about species competition for a limited food resource. The fish module is undergoing considerable development and evaluation at the Lake Wingra site.

Decomposition modules include a preliminary model for benthic invertebrates and a model of bacterial decomposition. The microbe decomposition model considers lake stratification and changes in oxygen levels in the sediments. In addition, bacterial decomposition is segregated into separate processes to simulate the effects of different bacterial types.

Individual modules are being subjected to intensive examination and validation. By developing the model in close contact with field researchers, it has been possible

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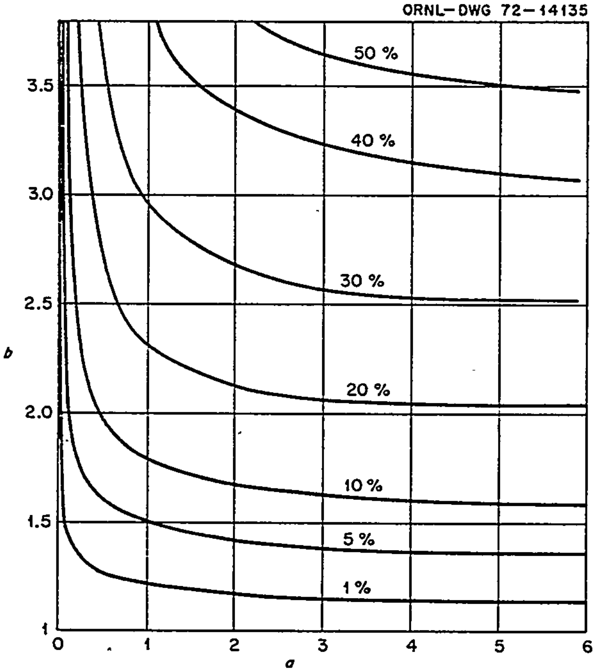

Fig. 5.2. Percentage error introduced by combining two populations into a single model variable when the populations differ in size by a factor a and differ in turnover rate by a factor b.

to incorporate considerable ecological insight. Continued modification and evaluation should produce a model of considerable value in adding to an understanding of lake ecosystems.

Linear models consist of sets of linear coupled differential equations. The dependent variables in the equations are the contents of the various biological and geophysical compartments of the ecosystem under consideration. Linear models have the following properties: First, the compartment values approach equilibrium if the system is allowed to run for a long time. Second, for an *N*-compartment model, there are *N* eigenvectors, each with its own eigenvalue. These determine the characteristic dynamic behavior of the system. In particular, the eigenvalues govern the time for the system to reach equilibrium from any specified arbitrary perturbation. Third, each compartment has a frequency response curve for sinusoidal input to the system. A program to develop a comprehensive analysis of these linear models of ecosystems began in April 1972.

A computer code has been developed which calculates the sensitivities of the steady-state values to changes in the transfer rate matrix of the differential equations. Significant values in the matrix may then be determined. Second, a code has been developed which calculates the changes in the eigenvectors with respect to changes in the transfer rate coefficients. Knowing these, sensitivities in the dynamic behavior of the system may be calculated. For the frequency response analysis, an existing program was modified to calculate the sensitivities of the frequency response curve to variations in the transfer rate matrix. For ecosystems with cyclical flow of materials, this program was further modified to compare the frequency response of the system to the response of the system when the cycles were broken.

On time scales of interest, nearly all biological processes are strongly nonlinear. The nonlinear nature of predator-prey relations has been long recognized, but the system of nonlinear equations around which much predator-prey research has revolved has been criticized by ecologists as being highly unrealistic. On the other hand, models complex enough to be satisfactory to ecologists are often too difficult to analyze mathematically. Research dealing with the analysis of a nonlinear predator-prey system is based on ecologically reasonable assumptions and, in addition, is simple enough to be accessible to a significant amount of mathematical analysis.

The model is concerned with the consumer portion of a terrestrial ecosystem. It consists of herbivores, to which a biomass input from the autotrophs is assumed, and further trophic levels of carnivores. The terms governing the rate of biomass change of any of the consumers include feeding, predation, respiration, excretion, and nonpredatory mortality rates. A unique feature of this model is its incorporation of a "saturation" effect with respect to predation. The nonlinear term representing predation becomes asymptotically proportional to the biomass of predators when the prey are easily available to the predators and proportional to the biomass of prey when the prey are relatively hard to obtain.

So far, systems involving two and three trophic levels of consumers have been considered, where the point of view has been to proceed as far as possible analytically before resorting to the computer. General expressions for the equilibrium biomasses and statements concerning ecosystem stability have been obtained in several limiting domains of values of the system parameters. Numerical computations are planned over ranges of parameters where mathematical analysis is not possible. A full understanding of the system will permit exploration of its applicability to natural systems. Of special interest has been the proof of the existence of "limit cycles," or steady-state oscillations of the system, for certain ranges of the parameters. This could be very important if a correspondence exists between these mathematical oscillations and periodic fluctuations of animal biomass observed in nature.

The Hydrologic Transport Model (HTM) is designed to estimate the time response of water flows and the associated transport of pollutants within a watershed. Among the many possible pathways for water are evapotranspiration, runoff, drainage, and storage within the soil layers. Since these phenomena are computed in a highly empirical manner in HTM, it has been decided to replace certain portions of HTM with an algorithm called PROSPER.

PROSPER is a phenomenological model which simulates the atmosphere-soil-plant moisture relations on a day-to-day basis. By applying a combined energy-balance–aerodynamic method and the principles of mass balance, evaporation from the litter surface, transpiration through the plants, the volumetric content of the different soil layers, and runoff can be calculated.

PROSPER is presently being modified to accept an arbitrary number of soil layers to be under the control of the user. Consideration is also being given to the techniques necessary to calculate not only vertical flow but also lateral flow in the soil layers.

A model was developed to study the dynamics of the atmosphere-soil-plant energy exchange system. The model consisted of two coupled nonlinear partial differential equations describing the transfer of sensible and latent heat and a coupled nonlinear ordinary differential equation describing the leaf energy balance. This system of equations was solved using a Crank-Nicholson algorithm for the partial differential equations and a Runge-Kutta algorithm for the ordinary differential equations.

The results of a limited number of simulation runs suggest that the steady-state model for the same system describes the system sufficiently well for most applications. This is particularly true since the computational algorithm is very expensive. However, improved techniques are being developed for solving partial differential equations of the diffusion type. Some effort should be spent in a reexamination of this problem as soon as these techniques are available.

Mathematical modeling is a rapidly expanding field in ecology. As a result, it is increasingly difficult to keep abreast of recent development. Particular problems arise from the numbers of internal reports with limited distribution. In a continuing effort to provide a centralized service, a series of modeling abstracts has been initiated. The project is designed to encourage contributions from active researchers and is closely coordinated with the Biome Information Center.

The abstracts cover a broad range of activities from theoretical modeling to applications of ecological models to environmental problems. Approximately 300 citations have been abstracted, and this number is expected to grow continuously as more investigators become involved in the project. The abstracts will be distributed in a continuing series approximately four times a year with complete author and key-word indexes.

BIOME INFORMATION CENTER

The Biome Information Center, designed to provide numeric and bibliographic services for Biome investigators, was operational throughout the year. Functioning within the Environmental Information System Office, the center implemented procedures for documenting and submitting data sets as a major accomplishment. In addition, the bibliographic input and retrieval has become routine, and services are regularly performed for the benefit of biome research.

A major activity has been the editing and production of a quarterly journal, *Abstracts, US/IBP Ecosystem Analysis Studies,* and three issues were produced containing (to date) 735 abstracts of ecosystem research.

Coordinating personnel at the major research sites are now available and assist with the interface between the individual sites and the Biome Information Center. This procedure was established to ensure proper and timely flow of numerical data sets into the Center, where accessibility and archival considerations are optimal.

6. Radiation Effects in Terrestrial Ecosystems

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SCOPE

Our heavy involvement with preparation of environmental impact statements for the AEC furnished a practical demonstration that previous radiation-effects research indeed was responsive to AEC programmatic needs. However, involvement in impact assessments effectively curtailed ongoing research projects this year.

Most of the research accomplished related to the effects of chronic low-level radiation on various components of terrestrial ecosystems.

EFFECTS OF SIMULATED FALLOUT RADIATION DEPOSITS ON POLLEN VIABILITY

Manifestation of a radiation effect on fescue grass – for example, reduced seed production, under circumstances of low-level field irradiation (10 to 21 rads/day) – prompted an investigation of possible effect on fescue pollen produced under similar exposure conditions. Differences in fescue pollen absorption normality were observed in our ^{137}Cs grassland facility between control and irradiated plants when total exposure was approximately 8400 rads – delivered at rates ranging from 17 rads/day initially to 4 rads/day three years later.

Average percentage of normal fescue pollen was consistently lower for the irradiated collections; average normal pollen per anther from irradiated plants was 5 percent units less than that of control areas (Table 6.1). Conversely, the average percent of aborted pollen from irradiated areas was nearly 6 units greater than that of controls. The 5-unit difference between irradiated and control probably is statistically significant, because the data are characterized by large N and small variance value. No differences were observed in percentages of aberrant pollen. Another sign of radiation effect on pollen viability was the frequency of anthers in which all pollen grains were aborted. Of 600 slides, each

Table 6.1. Percentage of normal, aborted, and aberrant fescue pollen from control and irradiated ^{137}Cs experimental areas

Data for each experimental area were based on a subsample of 20 panicles from an original sample of 60, and 5 pollen preparations per panicle. Thus, each value is an average of 100 determinations.

Plot	Normal	Aborted	Aberrant
	Irradiated		
2	87.1	11.5	1.5
5	79.3	20.4	0.2
7	84.4	11.6	4.0
Average	83.6	14.5	1.9
	Control		
4	92.8	6.3	0.9
6	89.9	7.5	2.6
8	87.5	9.4	3.1
Average	89.2	8.8	2.0

1. Temporary summer employee.
2. Dual capacity.
3. NSF-URP.
4. Consultant, St. Andrews College.

representing an anther, which were examined for treatment effects, occurrence of completely aborted pollen was ten times greater for irradiated anthers than for controls. This indicates that radiation damage to the derivative mother cell of the anther had greatest influence on anomalous pollen production as opposed to subsequent cell damage during later stages of spore formation when only individual or small groups of pollen spores would be affected. Dose rates were low (3 to 4 rads/day) during anther initiation and development, but reproductive tissues of grasses are initiated from meristems at the soil surface (which also was the zone of greatest radiation flux) and conceivably received as much as 500 rads total dose.

These results indicate that chronic exposure to low-level radiation from particle deposits indeed can cause a radiation effect. Under normal circumstances a 5% reduction in pollen viability would be a negligible consequence in situations of large-scale contamination of grass, because these plants typically produce very large amounts of pollen. Yet, there are special cases where self-pollination is common in cleistogamous plants (self-pollinating in the bud as opposed to cross pollination), and tall fescue possesses this characteristic. In this case, reproductive capacity may be diminished to a greater extent when both genomes originate from the same irradiated parent. Repeated cleistogamous reproductive events coupled with radiation-induced genetic damage in a native population could also result in reduced biological vigor over many generations. Furthermore, the effect may be manifested in important grain plants (barley, oats, wheat), because these species also exhibit cleistogamy in pollination.

RADIAL GROWTH OF *PINUS ECHINATA* AROUND AN UNSHIELDED REACTOR

The effects of ionizing radiation on natural plant communities have been documented from several sources of either gamma or mixed gamma-neutron radiation with a high proportion of gamma. The low radiation doses with a high proportion of fast neutrons delivered to vegetation around the Health Physics Research Reactor for the past nine years represent a unique opportunity to assess the impact on a forest ecosystem of this type of exposure under field conditions. Previous studies have shown growth retardation (needle length) and needle mortality for radiosensitive conifers to a distance of 40 m from the reactor.[5] The coniferous component of the forest within 40 m of the reactor has been eliminated by a combination of radiation damage and pine beetle infestation.

Increment core analysis for the 1955–71 period was used to assess the effect of chronic radiation exposure on radial growth of *Pinus echinata* at distances of 75 to 110 m from the reactor core (75 m is the current limit of encroachment by coniferous trees). Estimates of cumulative tissue dose in air were made by multiplying kilowatt-hours of reactor operation by dose-kilowatt-hour conversions determined by Witherspoon.[5] Cumulative fast-neutron dose (1963–1971) varied an order of magnitude from 39 to 110 m: 1500 rads at 39 m, 300 rads at 75 m, and 119 rads at 110 m. The fast-neutron to gamma ratio varied from 1.9 at 39 m to 1.1 at 75 m. Both cumulative dose and growth reduction approximate linear responses (Fig. 6.1). Reduction in radial growth was apparent during the first year of reactor operation, before gross morphological anomalies were observed. No visible radiation damage was observed in 1964 at distances >25 m (cumulative fast-neutron dose <154 rads).[5] Radial growth of *Pinus echinata* has decreased 8% per year from preoperation growth for cumulative fast-neutron dosage ranging from 298 rads (75 m) to 119 rads (110 m).

Analyses are in progress to determine (1) the interaction of chronic radiation and seasonal precipitation and (2) similar growth responses for forest tree species representing a tenfold range of radiosensitivity. More radioresistant tree species have quite different growth patterns. Preliminary analysis of increment growth of yellow poplar, for example, indicates an initial stimulation of growth which persists through 1967. The period of increased growth coincides with decreased growth (and eventual elimination) of pine; thus the decreased competition among trees initially appears to have a greater positive effect on yellow poplar growth than the negative effects accruing from chronic radiation exposure.

RADIATION EFFECTS AND RADIONUCLIDE EXCRETION IN A NATURAL POPULATION OF PINE VOLES

Excretion rates of ^{60}Co and ^{54}Mn and effects of acute gamma irradiation were measured in a dense natural population of pine voles (*Microtus pinetorum*) and compared with laboratory data for this species to ascertain if interactions among radiations, natural environmental factors, and population density cause responses different from those of animals in the laboratory.

5. J. P. Witherspoon, *Health Phys.* 11, 1637–42 (1965).

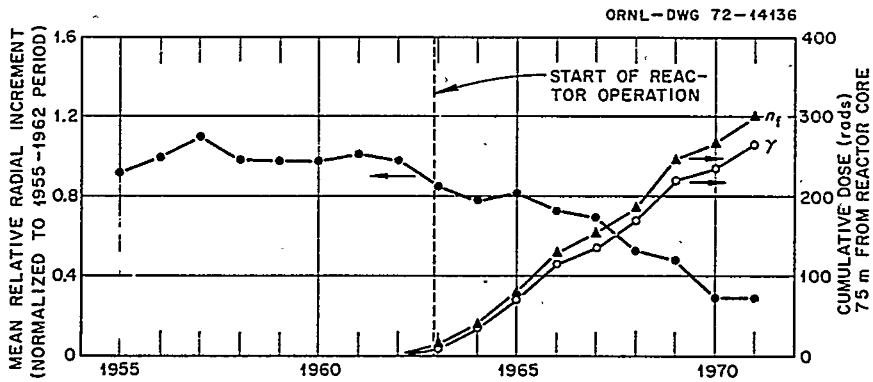

Fig. 6.1. Summary of mean relative radial increment of *Pinus echinata* trees growing 75 to 110 m from the Health Physics Research Reactor. Reactor operations commenced on May 31, 1963; cumulative fast-neutron and gamma exposures are shown. Radial growth responses of each tree (ten trees total) were normalized to individual annual average growth (1955–62).

Half of the population of 66 voles from a 1-hectare area was irradiated with a laboratory near-lethal dose of 700 rads, half was not. Irradiated animals received an injection of 1.09 μCi of ^{60}Co, nonirradiated animals received 1.00 μCi of ^{54}Mn.

Numbers of individual irradiated and nonirradiated voles recaptured during five months were not statistically different. Reproduction continued in both nonirradiated and irradiated females, but it contributed little to population recruitment. Both initial and long-term excretion of ^{54}Mn and ^{60}Co were significantly greater (thus, internal irradiation dose less) in the field than in the laboratory. The near-lethal dose of 700 rads caused no change in ^{60}Co excretion in the laboratory and only a slight reduction in ^{54}Mn excretion.

Results indicate that (1) radiation effects in the natural population were not significantly different from effects anticipated from laboratory experiments, except for the decreased recaptures of irradiated females; (2) natural environment factors caused faster excretion of ^{60}Co and ^{54}Mn than did irradiation or the laboratory environment; and (3) population dynamics and environmental factors were more important than the radiation as determinants of population status and radionuclide loss.

RESPONSES OF ARTHROPODS TO IONIZING RADIATION

Responses of arthropod communities to ionizing radiation as it interacts with other environmental parameters have been investigated in (1) short-term laboratory studies on interactions of radiation with population dynamics of selected species, (2) studies of the biological and physical dosimetry of beta and gamma radiation in a fallout area, and (3) long-term field observations on interactions of simulated radioactive fallout with seasonal changes in arthropod community composition and structure. Population dynamics of adults, juveniles, and eggs of *Sinella curviseta* (Collembola) were studied in the laboratory following acute doses of ^{90}Sr-^{90}Y beta radiation or ^{60}Co gamma radiation. Fecundity rates (eggs per adult per day) of adults were increased 48% by the lowest dose (1885 rads) of beta radiation, but fertility rates were reduced by radiation at all other doses. Gamma radiation was more effective than beta in reducing fertility rates. Juveniles were more sensitive than adults to both types of radiation, and day-old eggs were the most sensitive stage studied (Table 6.2). The increased effectiveness of beta radiation in young life stages is also indicated in Table 6.2. The juvenile stages do not have the chitinous layer developed to its maximum thickness, and eggs have no chitinous layer to shield them from beta radiation.

In the ^{137}Cs grassland facility, invertebrates (kind and number) were determined for 39 sampling periods over a three-year study. Dose rates to invertebrates over this time varied from 2.4 to 13.0 rads/day. Accumulated total doses at the end of three years in the grassland habitat of these invertebrates were 10.4 kilorads (42% gamma) at the soil surface, 8.6 kilorads (45% gamma) in the litter layer, 6.4 kilorads (56% gamma) in grass at 2.5 cm height, and 2.5 kilorads (92% gamma) in grass at 32.5 cm height. There were no significant differences in variation between numbers of soil-, litter-, and grass-inhabiting arthropods collected in field enclosures before application of fallout in summer 1968. Significant differences ($P \leqslant 0.05$) in variation between control and contaminated communities appeared in summer 1970 ($P \leq 0.05$), disappeared in autumn 1970, and reappeared in summer 1971 ($P \leq 0.01$). Thus population densities for 15 of 75 arthropod taxa had been affected from 1969 to summer 1971 in the radioactive area, but only eight populations were significantly smaller ($P \leq 0.05$). Recovery was noted for two of these eight in summer 1971. No significant increase in taxa composition dissimilarity between the contaminated and control areas has been observed. Consequently, the threshold for effects of fallout radiation on taxa composition of the arthropod community must be above the 2.4 to 13.0 rads/day delivered over three years.

Table 6.2. LD_{50} and RBE values (± standard error)[a] for beta and gamma irradiation of adults, juveniles, and eggs of *Sinella curviseta*

	LD_{50} (rads)		
	Beta radiation	Gamma radiation	RBE[b]
Adult ($LD_{50(30)}$)	30,000 (±833)	14,900 (±613)	0.497 (±0.017)
Juvenile ($LD_{50(30)}$)	22,460 (±703)	12,750 (±424)	0.568 (±0.020)
Egg ($LD_{50(14)}$)[c]	1,493 (±96)	1,390 (±83)	0.931 (±0.024)

[a] N = 3 replications.
[b] Standard errors for RBE values (gamma/beta) were propagated from LD_{50} values.
[c] One-day old eggs.

7. Applied Soils and Waste Management Studies

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Programs in radioactive waste disposal formerly in the Health Physics Division were transferred to the Chemical Technology and the Environmental Sciences divisions. The Hydraulic Fracturing and the Salt Mine Repository projects were assigned to the Chemical Technology Division; the projects dealing with Radionuclide-Soils Interactions and Toxic Elements in the Environment were transferred to the Environmental Sciences Division. Accomplishments in the Toxic Elements project are reported in another section of this report. This section describes progress in characterizing plutonium-soil interactions and in developing plugs to be used as sealants in the Salt Mine Repository.

CHARACTERIZATION OF PLUTONIUM-CONTAMINATED SOIL FROM THE NEVADA TEST SITE

This activity is part of a comprehensive effort (Plutonium Environmental Studies Program) to evaluate the potential hazard of plutonium at the Nevada Test Site (NTS). The objectives of this activity are (1) to determine the association of the plutonium with the various fractions of soils, (2) to characterize the plutonium in terms of availability and fixation in these fractions, and (3) to describe the potential movement of plutonium both into the soil and off the soil.

Plutonium behavior is difficult to determine accurately. As an alpha emitter, the radiation is easily attenuated; its unusual chemical properties, including several oxidation states, require exacting control during analysis; and its association with different transuranics, as well as with common soil elements, necessitates purification. Numerous procedures have been published regarding analysis for plutonium; most of them involve modification of one or more steps in the analytical procedure. Use of ^{236}Pu as an internal spike has been extremely useful; by adding a known activity level of ^{236}Pu and determining the yield of ^{236}Pu by alpha spectrometry, the original amount of plutonium in the sample can be calculated.

One of the most serious problems is the question of extraction. The addition of ^{236}Pu to soil prior to extraction may not necessarily reflect the total plutonium in soil. The ^{236}Pu is added in soluble form; its extraction, therefore, may be different than the more insoluble forms of plutonium in soil. For example, tests on bentonite which had been tagged with plutonium and then heated to 950°C before extraction showed that 12% of the plutonium was extracted in 2 hr of digestion with 8 *M* HNO_3. If such plutonium existed in a soil, the ^{236}Pu would be extracted, but the original Pu would not be extracted. The procedure finally adopted was the HNO_3-HF-HCl technique, supplied by G. Hamada, formerly of the Reynolds Electrical and Engineering Company at NTS; after appropriate modifications, this extractant, followed by ferric hydroxide and anion exchange purification and electrodeposition, resulted in 100% recovery, even with samples of plutonium-tagged bentonite heated to 950°C.

Further tests with 8 *M* HNO_3 extraction from bentonite, using 0.5 hr of digestion, showed decreasing extraction of plutonium with increasing heating temperature of the bentonite. All of the plutonium in bentonite heated to 40°C (104°F), to simulate desert soil temperatures, could be extracted under these conditions. Hence this extractant was selected for use on NTS soil prior to the HNO_3-HF-HCl for total extraction; the amount extracted with the HNO_3 would serve as a measure of the more easily extractable plutonium.

Results of the extraction from four surface soil samples are presented in Table 7.1. All samples were

1. Dual capacity.

Table 7.1. Plutonium extracted from 0–3 cm of NTS soil

In disintegrations per minute per gram. Numbers in parentheses are percent of sum

	HNO_3	HF	Sum	Total
Desert Pavement	1820 (80)	455 (20)	2275	2870
Blow Sand	1780(71)	720(29)	2500	2440
Microplot	2230(84)	430(16)	2660	2340
40 ft east of microplot	960(58)	680(42)	1640	1540

taken from areas representing "safety shot" tests; these tests used devices containing plutonium, but the detonation was by conventional explosives. The plutonium was scattered on the surface of the ground and now provides an excellent study area which contains only small quantities of fission products. The Desert Pavement and Blow Sand samples were taken at Area 5. The Pavement sample was taken from the bare soil area, whose surface contains approximately 10% gravel; the Blow Sand is a sample taken from the base of a creosote bush and appears to be windblown accumulation. The microplot sample and the sample taken 40 ft east of the microplot were obtained from Area 13. This area will be used for animal grazing experiments starting in 1973.

These samples were taken to provide activity levels which would permit determination of plutonium on different size and mineral fractions; they do not necessarily represent typical or representative concentrations at NTS. The results show that about 75% of the plutonium is extractable with nitric acid in three of the four samples. A slightly lower concentration was observed in the sample east of the microplot; the reason for this difference is not known at this time. A field instrument reading taken during sampling indicated the same level of activity in the microplot as in the area 40 ft east of the microplot.

The samples are being treated for size segregation and eventual mineral separation. The different size and mineral fractions will be analyzed for plutonium content. The Blow Sand sample contains discernible organic matter in the coarse size fractions; the organic matter will be separated and the plutonium concentration determined. After the initial survey of Areas 5 and 13 are complete and the data are evaluated, representative profile samples will be collected and analyzed.

PLUGGING OF BOREHOLES

This activity is part of the Salt Mine Repository project, now in the Chemical Technology Division. The project's ultimate objective is the development of a repository for high-level radioactive waste, as well as a repository of plutonium-bearing waste. In the explorations and ultimate development of this waste disposal facility in rock salt, boreholes will be drilled to secure detailed information on the geology of the site, and upon selection of the site, waste transport shafts will be constructed. These exploratory holes, and eventually the transport shafts, must be plugged effectively to assure protection of the repository from the action of aquifers above and below the disposal formation. Normal practice in the petroleum fields has been to plug wells with minimum cost plugs, and people familiar with the operation indicate that the plugs are not very effective. The objectives of this effort are to develop plugging materials for use in sealing boreholes, to test and evaluate the performance of the plugs under conditions simulating natural situations, and to define the conditions leading to failure and/or limits of applicability. Included in the objectives is the improvement of formulations of plugs to reduce or eliminate failure and to expand the limits of applicability.

Development of successful plugs requires knowledge of the formations into which the borehole has been drilled, the condition of the borehole, including the type and character of the aquifers in the formations, and applicable techniques of placing plugging materials in boreholes. To illustrate the requirements, consider the use of cement as the plugging material. Questions which arise include, among others, Which cement provides highest durability? How good is the bond with the various geologic formations, including the salt formation? What is the effect of drilling muds on the bond? What is the effect of brine or high-sulfate water on the durability of the cement? Should the cement be emplaced with scratchers, turbulent flow, and/or squeeze?

Fortunately, much information is available from oil well cementing firms. Presently, proposals are being evaluated from two established cementing companies, and a subcontract will be awarded to one to develop information on different plugging materials. This subcontract effort will be coordinated with the development work here, where emphasis will be on the use of natural earthen materials for primary plugging as well as for use as additives with other materials. Studies here have been initiated on evaluating cement as a potential plugging material. Cement, of course, is a common plugging material; however, long-term integrity of cement as a plug has not been evaluated. The data shown in Table 7.2 represent the type of information being observed with cement plugs. The permeability provides information on the movement of water through the

Table 7.2. The permeability of plugs and the calcium content and pH of eluate from different cements (water-cement ratio = 0.46) curing in 20° C water for indicated time at atmospheric pressure

Cement	Curing time (days)	Flow rate (ml/min)	Permeability (millidarcys)	Calcium (meq/ml)	pH
Type I	5	0.256	0.85	0.0028	11.0
	7	0.035	0.11	0.006	11.4
	19	0.006	0.02	0.0079	12.2
Type I with 50% pozzolan	5	0.171	0.55	0.035	12.1
	7	0.47	1.54	0.003	11.2
	19	0.003	0.01	0.013	10.4
Type S, expanding	5	0.032	0.10	0.0006	8.1
	7	0.027	0.08	0.0003	8.1
	19	<0.001	<0.003	0.0004	11.8
Type III	5	No flow for 24 hr			
Stress-Ex	7	0.01	0.02	0.0009	9.0
Type III with 50% pozzolan	5	No flow for 24 hr			
	7	No flow for 24 hr			

cement plug. Note that the expanding cement (type S) shows reduced permeability as compared with ordinary portland cement. On the other hand, the type III cement was most impermeable; however, all the tests are run under short curing time for the cement and relatively short test periods. What is needed is equipment to force water through at higher pressures (these tests were performed at 100 psi) for lower limit measurement of permeability and longer test periods.

The water which flowed through the cement was analyzed for calcium content and pH. The pH values substantiate that the more durable cement produces less calcium ions in the water. The continued loss of calcium would reduce the quality of the cement and eventually lead to degradation. Other information on the suitability of cement includes the bonding strength to formations. Although bonding strength was high (375 lb per square centimeter of contact surface) when the formation surface was clean, bonding strength greatly decreased (less than 10 lb per square centimeter of contact surface) when chemical mud normally used in Kansas was used to coat the walls of sandstone. Thus, if cement is to be used, the chemical mud must be removed prior to plugging, or possibly additives will be required to counteract the mud's effect on bonding.

Our more recent efforts have been directed to the potential use of natural earthen materials as plugging materials. This effort springs from the fact that long-term durability and integrity of man-made material, such as cement or polymers, are not known; and, to this date, no short-term tests have been devised which would definitively confirm long-term durability and integrity (10,000 years or more). On the other hand, minerals such as montmorillonite represent the end product of weathering as a result of given environmental regimes. Furthermore, these minerals have been used successfully for sealing purposes, primarily in dams and tunnels. Hence, the use of natural stable minerals appears promising if it can be demonstrated that they will form impervious seals to water finding its way to the borehole. Preliminary tests of flow rates of water through bentonite plugs are encouraging; the clay swells upon contact with water and seals the pores.

A column with a 2-cm layer of montmorillonite placed over a sandstone aggregate base has prevented water passage for a week at 100 psi pressure; the aggregate originally flowed at about 50 ml/min (atmospheric pressure) without the clay.

It is anticipated that, following laboratory development of information on sealing materials, several field tests will be conducted in the neighborhood of the repository to evaluate various plugs.

8. Toxic Materials in the Environment

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The Toxic Materials in the Environment project is part of a larger and more comprehensive program of Ecology and Analysis of Trace Contaminants supported at ORNL by the NSF/RANN. The Ecology and Analysis of Trace Contaminants program consists of 15 separate tasks and includes personnel from 10 ORNL divisions. These tasks comprise a broad program of research on the environmental effects of trace substances. The Toxic Materials in the Environment project, which is carried on in the Environmental Sciences Division, emphasizes studies of trace substances themselves – their levels, fates, and pathways. The research activities within this project are building upon expertise developed in studies of Radionuclide Cycling in Terrestrial and Aquatic Environments. A holistic approach is being taken in the assessment of toxic material movement through ecosystems, and includes emphasis on biological forms, distribution, and availability of heavy metals in water, soils and sediments, soil-water-plants, and food chains. Our first year's progress in these areas is reported below.

ENVIRONMENTAL MONITORING OF TOXIC MATERIALS IN ECOSYSTEMS

This task addresses itself to developing a series of trace contaminant profiles in major forest ecosystems in East Tennessee. Another responsibility of this task is interfacing with the remaining 14 tasks of the Ecology and Analysis of Trace Contaminants Program to develop a base-line data base on toxic materials in the environment. In conjunction with this latter objective, a toxic/trace contaminants profile in vegetation, soils, and sediments around a major fossil-fuel power production facility is being developed.

Biogeochemical Survey of Trace Elements in Ecosystems

Prior to the establishment of our trace element monitoring project and the related toxic element balance of a forested watershed, a biogeochemical orientation survey was initiated on Walker Branch Watershed. The ultimate objective is to scan concentrations of Pb, As, Zn, Hg, Co, Fe, Mo, Ce, Be, Sr, Se, Ag, Cs, Cd, V, F, Cr, Cu, Sb, Ni, Mn, and Cl in

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environmental samples using spark source mass spectrometry. Resulting trace element profiles in soils and vegetation will be utilized to establish the toxic materials monitoring scheme and provide preliminary source terms for the environmental transport modeling efforts.[7] Specific objectives are to (1) provide base-line concentrations of micronutrient and trace element concentrations in environmental samples, (2) establish historic trends of element concentrations in ecosystem components, (3) evaluate intra- and interspecies and seasonal variations, (4) survey for potential indicator species which accumulate certain elements, and (5) develop mass balance budgets of trace elements for a forested watershed.

In a collaborative project with Brock University, Saint Catherines, Ontario,[8] we began a comparative geochemical survey of chemical elements in contrasting forest ecosystems on glacial (Ontario) and residual (Tennessee) soils. In the Oak Ridge component, a 160-m transect was established on Chestnut Ridge spanning a 40-m elevational transect from ridgetop to streamside. Soil series included Fullerton and Bodine on dolomite parent material. Vegetational associations included pine, beech, maple, hickory, tulip poplar, and chestnut, red, and white oak. Chemical data from soil pit profiles are just recently available for Pb, Cu, Zn, Fe, Mn, Mg, and Al (Table 8.1). Lead, copper, and zinc exhibited marked accumulation in upper soil horizons. Whether concentration patterns were related to complexing on soil organic matter and/or reflected external input to the system has yet to be evaluated. Iron, magnesium, and aluminum show highest concentrations in upper soil horizons and progressively decrease with depth of the profile to 90 cm. Magnesium shows inputs from parent material in residual mineral soil, while iron displays characteristic lowest concentrations in the A horizon from leaching. Manganese levels were variable but were generally highest in the 0-to-30-cm strata and decreased rapidly thereafter. Future interpretations of soil chemistry will evaluate slope, soil characteristics, and vegetation cover as variables. Analyses of woody increments in bole over the past 50 years will be used to assess whether patterns of distribution of Pb, Cu, and Zn are due to internal cycling or reflect recent inputs to the system from external sources.

Table 8.1. Ranges of elemental concentrations (parts per million of dry soil) in Fullerton and Bodine series ($N = 8$) from Walker Branch Watershed

Soils are formed from dolomitic limestone parent material and span a 40-m elevational transect from ridgetop to streamside.

Element	Upper 3 cm, mixed organic matter and mineral soil	Residual mineral soil, ≅90 cm depth
Lead	18–54	1–9
Copper	2–7	<1
Zinc	9–39	1–3
Iron	970–2920	270–1680
Magnesium	38–291	6–639
Manganese	338–3575	1–88
Aluminum	600–4400	500–2700

Trace Contaminants Measurements at and around the Allen Steam Plant Facility

Coal-fired power plants are responsible for about 46% of electrical production in the United States. Annual consumption of coal for this use amounts to about 3×10^{14} g of coal per year. Coal has been shown to contain trace quantities of potentially hazardous elements: Hg, Cd, V, Zn, Ti, Pb, Ni, U, and others. Mercury, for example, occurs in some U.S. coals at levels of about 0.2 ppm; and assuming that this represents a national average, then the equivalent mercury involved is 60 metric tons annually. Part of this material is emitted from the stack and is transported through the atmosphere to areas surrounding power plant sites, where it may accumulate in soils, sediments, and vegetation, thus providing several entries into food chains, potentially leading toward man. The remainder of the material is retained in fly ash trapped by electrostatic precipitators or is present in the bottom slag from the boiler. These materials are deposited in ash ponds, and some will be released directly to rivers and streams via pond outflow. The availability to aquatic organisms of the associated toxic elements is unknown.

To learn more about the disposition of toxic elements associated with coal combustion, the TVA Allen Steam Plant, on the Mississippi River, in Memphis, Tennessee, is being studied under sponsorship of the NSF/RANN program "Electrical Energy and Its Environmental Impact." The work consists of two parts: (1) in-plant sampling in an attempt to obtain a mass balance for as many elements as possible[9] and (2) sampling in the environment in an attempt to measure any enrichment due to plant discharges of the various elements in the

7. "Ecology and Analysis of Toxic Contaminants," proposal to NSF/RANN Program from ORNL.

8. J. A. C. Fortescue, Geology Department, co-principal investigator.

9. In-plant sampling is being done by ORNL Health Division personnel in collaboration with TVA. Analytical measurements are being made by the ORNL Analytical Chemistry Division.

ambient air, the soil, plant life, or water, sediment, and biota of the stream receiving the ash pond outflow.

From samplings made at the Allen Steam Plant in early 1972, a reasonably good balance of many elements in coal with the waste products from combustion has been obtained. Since gas-phase sampling around the precipitators and in the stack focused primarily on collecting particulate matter, a good balance was not obtained for elements forming volatile compounds in combustion. Mercury is notable in this regard, since only 17 to 20% was found in bottom slag and fly ash. The rest was not accounted for and probably escaped via the stack,[10] presumably in the vapor state.

To date, two 15-cm-deep soil cores have been collected at 1-mile intervals along the 40-mile north-south transect corresponding to the prevailing wind direction. Analyses for Hg, Pb, Cd, and Cu are given in Table 8.2. Considerable variation of concentration was found with distance for these and most of the other elements measured. In particular, peak concentrations were observed at 2 to 5 miles south of the plant and at 6 to 10 and 14 to 17 miles north. However, it is concluded that no appreciable part of the soil concentration variations can be attributed to the steam plant, since none of the cores showed significant variations with depth for any of the elements, and the soil concentrations for a number of elements showing the variations with distance were equal to or greater than those found in the fly ash.

10. C. E. Billings and W. R. Matson, "Mercury Emissions from Coal Combustion," *Science* 176, 1232 (1972).

Table 8.2. Toxic metal concentrations (parts per million of dry weight) in the top 2.54 centimeters of soil core samples obtained from a north-south transect at the Allen Steam Plant in Memphis, Tennessee

Values represent means from two samples collected at each site. Mercury analyses were by atomic absorption spectroscopy (total digestion), and Pb, Cu, and Cd were by isotope dilution spark-source mass spectroscopy (acid leachable)

Mile	Concentration			
	Cd	Cu	Hg	Pb
North 20			0.028	
19	0.44	16.5	0.024	10
16		41	0.059	20
14		20	0.067	75
12	1.8	19.5	0.031	19.5
10	3.5	24	0.034	38
8	1.2	64	0.046	5
6			0.042	11
4	1.52			
2	0.84	16	0.030	17
South				
2	0.34	18	0.023	30
4	1.2	20	0.044	18
5	0.7	15	0.029	28

ZONAL CENTRIFUGATION: APPLIED ASPECTS IN ELUCIDATING CHEMICAL AND BIOLOGICAL FORMS, DISTRIBUTION, AND AVAILABILITY OF HEAVY METALS IN THE ENVIRONMENT

This task is directed toward determining the location, chemical form and concentration, and biological availability of heavy metals associated with the organic and inorganic components of sediments and soils through the use of density-gradient zonal centrifugation. Zonal centrifugation is quite useful for density separations of heterogeneous mixtures such as soils and sediments. Each separated component is then available for characterization and analysis. The research reported here describes an application of the zonal centrifugation technique to mineral (TiO_2) separation, and the evaluation of factors affecting uptake and assimilation of cadmium from soil by plants.

Anatase Separations

The southeastern United States possesses large deposits of kaolin minerals, many of which contain anatase, a titanium mineral (TiO_2) interfering with commercial use of this clay mineral. The density of kaolin clays ranges from 2.60 to 2.65 g/cm^3, while the titanium mineral is considerably denser, ca. 4.0 g/cm^3. Thus zonal ultracentrifugation separations in appropriate density gradients should be a satisfactory method of removing anatase from kaolin.

Three raw kaolin samples (K-I, K-II, K-III), containing 0.95, 1.53, and 0.98% TiO_2, were used to evaluate the effectiveness of zonal ultracentrifugation for anatase removal. These kaolin samples were centrifuged across density gradients 2.4 to 2.9 g/cm^3 at 12,500 rpm in a model L-2 Beckman centrifuge for 20 hr (26.7×10^3 *g*). The titanium found in the material passing through the gradient (density >2.9 g/cm^3) was considered to be anatase, while that remaining in the kaolin band (density 2.4 to 2.6 g/cm^3) reflected either incomplete anatase removal or titanium indigenous to the 1:1 layer silicate. The fraction of titanium remaining in the banded kaolin ranged from 72 to 55% for the three clays (Table 8.3). At present it is not known how much of the titanium in the banded samples represents titanium within the clay crystal lattice. The closeness in ionic size of Ti^{4+} with Al^{3+}, 0.68 and 0.50 Å radii,

Table 8.3. Titanium concentrations of kaolin before and after purification by zonal ultracentrifugation (density gradient 2.4 to 2.9 g/cm^3)

Kaolin type	Percent titanium		
	K-I	K-II	K-III
Raw	0.57	0.92	0.59
Banded	0.41	0.51	0.36

respectively, allows some isomorphic substitution. It is significant that in one clay (K-II), nearly one-half of the titanium can be separated as anatase.

Plant-Soil Interactions

Culture solutions were utilized in determining nutrient factors governing cadmium uptake in plants. Calcium concentration and pH were varied in solution and in ^{109}Cd-contaminated soils. Comparison of cadmium uptake in plants from nutrient solution to that from soil illustrates the influence of soil and formation of soil-cadmium reaction products. After sufficient reaction time, separation of these reaction products will be attempted by zonal centrifugation. The availability of these reaction products will be evaluated in future experiments through plant uptake of cadmium in nutrient solutions. In the initial phases of this work, nutrient solution pH and concentrations of Ca, N, Zn, and Se were varied while determining ^{109}Cd assimilation in plants.

Cadmium-109 concentrations were significantly greater in plants grown in the solutions of lower pH. Dry matter production of roots, stems, or leaves at the various pH levels were not significantly different ($P \leqslant 0.05$). Translocation of ^{109}Cd (the ratio of the ^{109}Cd concentration in leaves relative to that in roots) to the foliar portions of the plant was greatest when the pH was highest. Thus the factor limiting cadmium availability appears to be the solution chemistry of cadmium and not the physiology of the plant.

Similarity in the size of ionic radii of calcium and cadmium (0.97 and 0.99 Å respectively) indicated that changes in calcium availability would alter cadmium assimilation by plants. A significant ($P \leqslant 0.05$) decrease in ^{109}Cd concentrations in the leaves and stems of bush beans was noted on increasing applications of $Ca(NO_3)_2$ to nutrient solutions. Significantly higher concentrations ($P \leqslant 0.05$) of ^{109}Cd were found in the upper leaves than in the lower leaves, which indicates that translocation of cadmium occurs early in the leaf development.

Within biological systems, it is recognized that group II-B elements (Zn, Cd, and Hg) compete for certain enzyme sites. In the present study, zinc additions significantly increased ^{109}Cd concentrations in bush bean stem and leaf tissue but significantly lowered ^{109}Cd concentration in the roots. Levels of 100 ppm zinc in nutrient solution greatly reduced dry weight production, and 10 ppm appears to have lowered the weights of roots and leaves. These data indicate enhancement in cadmium uptake at higher zinc levels. Significantly ($P \leqslant 0.05$) lower quantities of ^{109}Cd were taken up by bush beans grown in nutrient solutions containing 0.1 ppm selenium than in solutions of 0.001 ppm selenium. After seven days' growth, amendments of selenium did not affect plant growth, as there was no significant difference in dry matter production.

Cadmium-109 concentrations in Japanese millet were significantly lower when grown in soil amended with calcium carbonate than when grown in soils of pH 5.1. This was true regardless of the form of ^{109}Cd utilized (chloride or oxide). In the first harvest of Japanese millet, foliar cadmium concentrations were significantly ($P \leqslant 0.05$) higher when the chloride form was used. However, in the second harvest, only plants grown in the unlimed treatments showed differences in cadmium concentrations between the two forms. In neutral to alkaline soils three months following application, the form of cadmium has only minimal affect on plant uptake of cadmium.

TOXIC METALS IN LAKE AND STREAM SEDIMENTS

This task of the Toxic Materials in the Environment project includes the determination of the factors controlling the distribution of toxic elements in the different components of water systems and the analysis of cadmium and zinc in selected river systems of the zinc-producing region of East Tennessee.

Heavy Metal Behavior in Mineral and Sediment Systems

Suspended and bottom sediments in natural rivers and lake systems consist primarily of minerals. The most common of these minerals, clays, are the most reactive in adsorbing dissolved ions. In contrast to the clay minerals normally found in these systems, reference minerals are well characterized and thus provide the basis for defining the significant factors in adsorption of the toxic elements. From this base, we may then proceed to compare naturally occurring clays from the water system and their adsorption with the results of the reference clays. Previous work with other trace elements (namely, strontium, cobalt, and zinc) has shown that adsorption was strongly influenced by pH. The pH range of greatest influence is between 5 and 8; this is the common pH range of natural waters. The role of pH is both direct and indirect. As a competitive cation, the hydrogen ion concentration is in the same order of magnitude as the trace contaminant. Its indirect role is its ionization from surface hydroxyls of clays and other components in sediment systems, namely, iron and aluminum oxides and hydrates.

Because of the above considerations, reference clay minerals were used to determine the selectivity coefficient of cadmium in calcium acetate solutions over a pH range of 5 to approximately 8. Increasing coefficients were found in the order: illite > kaolinite > vermiculite > montmorillonite. With increasing pH, the coefficient increased for all minerals. The highest measured coefficient was 850 for illite at pH 7.75; the lowest was 3.4 for montmorillonite at the same pH. From pH 5 to 7.5 the coefficient increased by a factor of 4 for montmorillonite, by 30 for vermiculite and kaolinite, and by 45 for illite. The low selectivity and small increase at higher pH observed with montmorillonite are consistent with the known characteristics of the mineral. The high selectivity of illite is believed to be due to its high charge density and the dissociation of edge hydrogen from the hydroxyls. The next phase of this work will include determination of selectivity coefficients for cadmium in some naturally occurring clay soils and correlation of these coefficients with plant availability.

Cadmium and Zinc in the Holston River and Joe Mill Creek

These two river systems were selected for study from the zinc mining district of East Tennessee. Joe Mill Creek is a small stream that flows over a dolomite outcrop (which is the zinc-bearing formation); the Holston River at Mascot, Tennessee, formerly received part of the washings from the zinc beneficiation plant. Samples of water and bottom sediments were collected from these sites and analyzed for zinc and cadmium after different treatments designed to provide information on the amount, chemical forms, and distribution of each element.

The cadmium and zinc contents in the water of the two systems after removal of suspended particulates were, respectively, 0.0018 and 20 ppm in Joe Mill Creek and 0.0028 and 50 ppm in Holston River. The Holston River samples represent the half-mile interval downstream from the point of discharge of Big Flat Creek, which flows into the Holston. The cadmium content of these two water systems is below the 0.010-ppm upper limit for drinking water recommended by the World Health Organization. The bottom sediments averaged 6 ppm cadmium and 300 ppm zinc in Joe Mill Creek and 26 ppm cadmium and 4500 ppm zinc in the Holston River. Over 75% of the particulate material in bottom sediments of both rivers is sand sized, and the major mineral is dolomite. To date, only Joe Mill Creek samples have been analyzed for cadmium in the different particle sizes; the results suggest that the bulk (65%) of the cadmium is in the sand sizes.

The suspended sediment load at the confluence of Big Flat Creek with the Holston was relatively high (160 ppm) but rapidly decreased downstream (12 ppm at 0.5 mile). The source of the sediment was the washings from the ore beneficiation plant. The suspended sediment load in Joe Mill Creek is relatively low (about 5 ppm) at the outcrop zone; 1.5 miles downstream the load is approximately 25 ppm; the increase is due to additions from side stream sources. There is a significant difference between the suspended particulates of the Holston River and Joe Mill Creek in that the suspended sediments of Joe Mill Creek contain higher concentrations of cadmium relative to bottom sediments than do those of the Holston River. Suspended particles in Holston River water contained approximately the same concentration of cadmium as its bottom sediment, suggesting an identical source of the metal.

ECOLOGY OF TOXIC METALS

The objective of this task is primarily the evaluation of heavy metal behavior in aquatic and land-water systems. This evaluation includes determination of the rates of transport through freshwater streams, the biological turnover and food chain accumulation of heavy metals as affected by different physical and chemical factors, and the rate of movement of toxic metals from terrestrial to aquatic ecosystems. This report summarizes our initial efforts in these areas.

Cadmium Stream Tag

In an effort to understand the behavior of cadmium in aquatic ecosystems, a 100-m segment of an oligotrophic stream was tagged with 5 mCi of $^{109}CdCl_2$. Water samples were taken for the duration of isotope flowthrough. These samples were filtered to determine the extent of adherence of the ^{109}Cd to suspended particles. Samples of sediments, periphyton, watercress, snails, and fish were collected weekly for seven weeks.

Ninety-five percent of the initial ^{109}Cd activity was retained in the 100-m stream section. About 20% of this activity was found adhering to suspended material in the water column at 100 m. The concentration ratios for ^{109}Cd in the ecosystem components (concentration in component/concentration in water) are shown in Fig. 8.1. Sediment samples show a general decline in radioactivity with time as ^{109}Cd is leached. Watercress lost most of the initial activity within three weeks. The periphyton activity at seven weeks had declined by a factor of 3, and the snails that graze on the periphyton had declined by a factor of 2. Fish accumulated cadmium, with most of the activity found in the viscera. Muscle concentration ratios seldom approached 1.

Mercury Transfer in an Aquatic Food Chain

Accumulation of mercury in fish is one of the most important aspects of the mercury pollution problem, both in terms of ecological effects and human consumption. Fish acquire body burdens of mercury directly from the water by absorption through the gills and through the food chain. There have been many analyses of mercury in aquatic organisms, but the trophic dynamics of mercury in aquatic ecosystems remain obscure. Understanding the trophic dynamics requires consideration of the food chain behavior of both inorganic and organic mercurials. Elimination rates and efficiencies of transfer of CH_3HgCl and $Hg(NO_3)_2$ acquired via the food chain detritus–*Chironomus* larvae–*Gambusia*–*Micropterus* at 25° were experimentally determined.

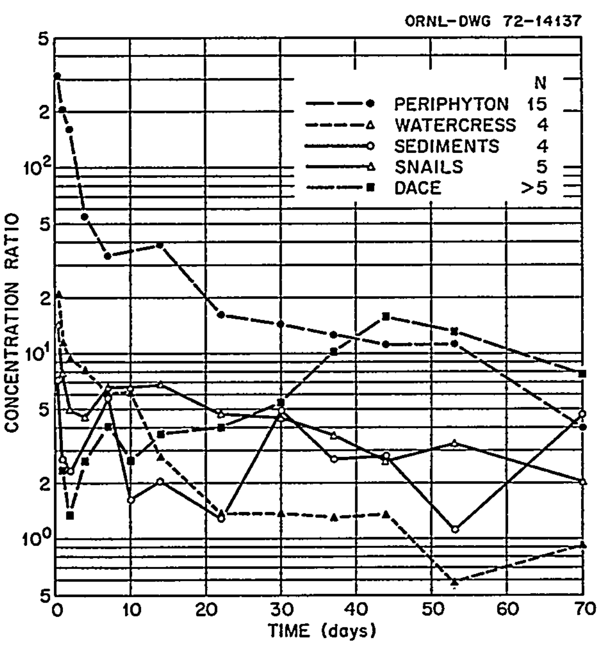

Fig. 8.1. Cadmium concentration ratios (^{109}Cd in animal/^{109}Cd in water) of stream ecosystem components following an acute input of $^{109}CdCl_2$.

Table 8.4. Biological half-lives (T_b in days) and assimilation efficiencies (a = percent of ingested mercury found in blood after a single feeding) of CH_3HgCl and $Hg(NO_3)_2$ in an aquatic food chain at 25°

	Direct uptake		Food chain uptake	
	CH_3HgCl	$Hg(NO_3)_2$	CH_3HgCl	$Hg(NO_3)_2$
Chironomus				
T_b	48	0.5	7	5.5
a			85	60
Gambusia				
T_b	77	14	55	12
a				
Micropterus				
T_b		27		12
a				40

Table 8.4 shows the values that have been determined for biological half-lives and assimilation efficiencies for mercury obtained from both water and food. In all cases, methylmercury is taken up to a greater extent and retained longer than $Hg(NO_3)_2$. The mechanism of uptake and retention of inorganic mercurials by fish differs from that of organic mercurials. Inorganic mercurials are metabolized in the liver and excreted via the kidneys. The more stable organic mercurials are not excreted readily and are deposited in the nervous systems and muscles. Since fish muscle protein has a higher percent of sulfur-containing amino acids and nitrogen, both of which react readily with mercury and other heavy metals to form stable chelates, fish muscle tends to contain relatively higher mercury concentrations compared to muscle in other organisms.

Hannerz[11] has compared direct uptake and food chain uptake of several forms of mercury by both marine and freshwater fish. He concluded that food chain accumulation of inorganic mercurials in freshwater fish seems negligible and that his experiments led to an overestimation of the role of accumulation of mercury from food. He warned that his data cannot be

11. L. Hannerz, *Inst. Freshwater Res., Drottingholm* 48, 120–76 (1968).

used to make any conclusions as to the relative importance of mercury uptake from the water and from food in nature. Jernelov[12] reported that in nature the transfer of methylmercury from benthic organisms to benthic-feeding fish is small but that for pisciverous predators (pike), 60% of the mercury body burden is acquired through the food chain. These calculations are based on analyses of stable mercury from fish collected in Swedish waters. Our experimental data (Table 8.4) indicate that food chain accumulation can contribute significantly to fish body burden of mercury.

Fly Ash Microcosm Study

The discovery of high concentrations of mercury in organisms remote from mercury ore bodies or pollutive discharges led to the identification of fossil-fuel burning as a source of regional mercury contamination. The average mercury concentration in coal has been reported to be from 0.2 ppm to 3.3 ppm, but $\geqslant$1.0 ppm appears to be about average for most American coal.[13] There are no reports of measurements of the mercury concentration of coal fly ash collected in areas distant from the stacks where it was discharged, but fly ash collected from stack precipitators has been shown to contain 0.2 ppm mercury, while the coal contained 0.3 ppm mercury.[14] The same authors calculated that 90% of the mercury in the coal was lost out of the stack to the environment during normal furnace operations.

Mercury in coal is converted to the vapor phase in the furnace when the coal is burned but condenses as Hg^0 on fly-ash particles when the temperature drops as the fly ash and flue gas stream ascend the stack. Mercury from coal is thus introduced into the environment in the metallic form (perhaps some as HgO), adhering to particles of fly ash which ultimately settle out of suspension at points distant from the stacks. The environmental impact of mercury-bearing fly ash has not been adequately monitored or assessed. In order to determine the quantity and availability of mercury from fly ash to an ecosystem, fly ash was collected over a period of seven weeks and analyzed for mercury by heating the sample to 800° for 0.5 hr in a muffle furnace, collecting the mercury in a dilute HNO_3 trap, and analyzing it by atomic absorption spectrophotometry. The fly-ash samples averaged 0.98 ppm mercury. Some of this fly ash was tagged with radioactive ^{203}Hg and applied in a water suspension to laboratory microcosms to directly test the uptake, retention, and cycling of ^{203}Hg from fly ash by the biota.

The microcosms, half stream bank and half stream bed, were established in April 1972. Stream sediments, *Goniobasis* snails, and *Gambusia* (mosquito fish) constituted the aquatic portion of the microcosms. The terrestrial half was an intact section of stream bank. The microcosms were watered twice a week to simulate the natural rainfall of the area. Samples, including soil, litter, sediments, water, snails, and fish, were assayed for ^{203}Hg content weekly. Figure 8.2 illustrates the increasing concentrations of ^{203}Hg in the aquatic subsystem. Mercury concentrations in fish and snails tended to remain fairly constant, whereas the sediments accumulated the mercury quite rapidly and increased in concentration by an order of magnitude during the 130-day experiment. The terrestrial subsystem had an uneven mercury distribution, since plant growth was rather dense at the time of tagging, and fly-ash particles were consequently deflected during the tagging procedure.

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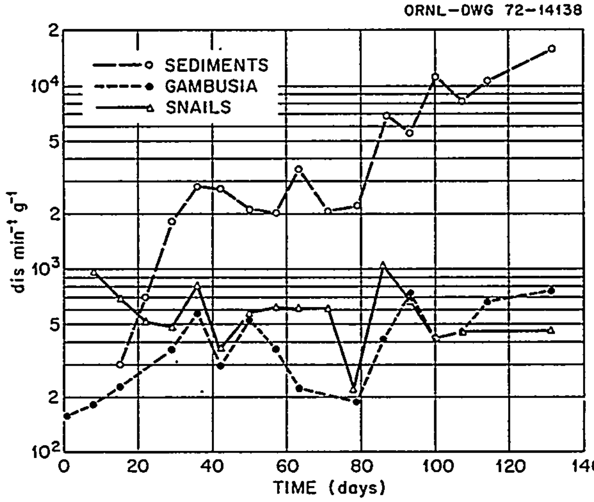

Fig. 8.2. Mercury-203 concentrations in three components of a microcosm system tagged with ^{203}Hg (fly ash) expressed as a function of time.

12. A. Jernelov and H. Lann, *Oikos* 22, 403–6 (1971).
13. J. V. O'Gorman et al., *Appl. Spectrosc.* 26, 44–48 (1972).
14. M. D. Schlesinger and H. Schultz, *U.S. Bur. Mines, Tech. Publ.* 46 (1971).

9. Environmental Hazards Evaluation

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This activity is concerned with evaluating the impact of radionuclide releases to the environment. Previous to May 15, 1972, this program was administered by the Health Physics Division. The research is now organized in the Environmental Sciences Division under two projects: One project involves development of guides to assess any releases of radioactivity to the environment, while the other project deals with evaluation of radiological exposure to populations from Plowshare applications.

The primary objective of our efforts at evaluating environmental releases of radioactivity is to develop a methodology that is reasonable, practical, and accurate for assessing radiation exposures of human populations via all important exposure modes. This effort requires a detailed knowledge of the potential pathways for transfer of environmentally released radioactivity to man, in addition to description of the habits and biological parameters of man which influence radiation dose. The approach is to develop mathematical simulations of selected environmental transport systems (e.g., a crop system, a pasture system, an aquatic system, etc.) to predict the fraction of released radioactivity reaching man. One end point of the radiological assessment is an index identified by the acronym CUEX, which stands for "cumulative exposure index." The numerical value of CUEX for a specific radionuclide release reflects the magnitude of the estimated total dose to individuals or populations relative to a selected dose limit.

Methods developed under this project are being applied in the radiological section of detailed environmental impact statements prepared at ORNL for the AEC to meet the requirements of the National Environmental Policy Act of 1969. This strong tie with the civilian nuclear power program contributes to a better understanding of the radiological aspects of power reactors in relation to potential exposures of human populations and is a useful testing ground for the relevance and practicality of our developing methodology.

The second project provides support to the AEC's Plowshare Program in the area of radiological dose assessment. The principal effort is devoted to estimating radiation doses to individuals and populations resulting from plant processing and home consumption of nuclearly stimulated natural gas. The objective of these studies over the next several years is to provide sufficient background information (1) to evaluate the feasibility of using nuclearly stimulated gas in households and in industry and (2) to provide sound information on which radiological regulations may be established.

A critical situation has developed in the United States energy picture because of dwindling domestic reserves of natural gas and increased demands for this nonpolluting energy source. This project in the Environmental Sciences Division is responsive to the AEC's Plowshare objectives of developing a commercial technology to nuclearly stimulate substantial quantities of natural gas in four to five years. Two tests of the gas stimulation concept, Gasbuggy and Rulison, have been completed,

1. Reactor Chemistry Division.
2. Instrumentation and Controls Division.
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5. Analytical Chemistry Division.

and others are planned. Our studies to date indicate that the long-lived radionuclides, principally tritium and ^{85}Kr, are the important contributors to dose. Commercial development of this peaceful application of nuclear explosives will depend on public acceptance of the exposure risk as well as on the economic aspects. Our efforts continue to be directed at studying all aspects of the exposure pathway risks associated with production and utilization of nuclearly stimulated natural gas.

DEVELOPMENT OF RADIATION SAFETY GUIDES FOR ENVIRONMENTAL RELEASES OF RADIOACTIVITY

Development of methodology for assessing environmental releases of radioactivity is the primary objective of this activity. A cumulative exposure index (CUEX) incorporating considerations for radiation exposure of human populations via all important exposure pathways has been suggested as one end point for such assessments. The formulation for calculating CUEX has been detailed previously.[6] The numerical value of CUEX for a specific radionuclide release (time-integrated concentration in an environmental medium) reflects the magnitude of the estimated total dose relative to a selected dose limit. The dose limit used in making an assessment may be one applicable to exposures of individuals (rem) or one applicable to exposures of populations (man-rem). Because the exposure limits are expressed in units of dose, the methodology for calculating CUEX, of necessity, embodies environmental models to convert measured environmental radionuclide concentrations into estimates of radiation dose to man. Mathematical simulations are developed for use as modules in construction of environmental models to predict the fraction of each released radionuclide exposing man as a function of time at any given location. A generalized model has been developed to quantitatively predict radionuclide movement through terrestrial food pathways.[7] An aquatic food pathway model to supplement the terrestrial model is in a preliminary stage of development.

Comprehensive demonstrations of CUEX are just as important as the modeling refinements within the methodology. Preliminary plans have been completed for application of CUEX to assess radionuclide releases from several nuclear power stations. Site-specific data are to be utilized to predict the environmental behavior of all radionuclides expected to be released, and possible radiation doses to man are to be estimated and assessed (first-generation CUEX's). Subsequent to the start of plant operation, environmental monitoring data are to be used to verify the adequacy of the models or suggest model adjustments wherever needed (second-generation CUEX's). Once CUEX's are calculated for a site, they are expected to serve as the primary tool for assessing the radiological significance of all future radioactivity releases at that site. The radioactivity releases may range anywhere from the continuous effluents of normal plant operations to the transient escapes of radioactivity predicted for major reactor accidents. The most accurate creditable CUEX's will evolve from a broad base of site-specific environmental data and plant monitoring experience. That is not to say that the methodology for calculating CUEX is intended for use only at sites which have been studied in great detail; the methodology is expected to be equally valuable in the hands of an experienced user who is asked to make a rapid first-cut assessment for radioactivity released to the environment. To prepare for a demonstration of CUEX in this application, the potential source term (radioactivity to be released) must be characterized in detail. A portion of this work has been completed,[8] and it is summarized elsewhere in this section of this report. The long-term goal of the demonstration program is to refine the methodology for calculating CUEX and illustrate its use in a variety of applications.

RADIOLOGICAL SUPPORT ACTIVITIES FOR ENVIRONMENTAL IMPACT STATEMENT PREPARATION

The Environmental Hazards Studies Group provides technological and advisory support to other groups engaged in the preparation of environmental impact statements. Methods developed under the CUEX program were used to complete radiological sections of all environmental impact statements prepared at ORNL

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6. S. V. Kaye, R. S. Booth, P. S. Rohwer, and E. G. Struxness, "A Cumulative Exposure Index (CUEX) for Assessing Environmental Releases of Radioactivity," pp. 909–22 in *Proceedings of International Symposium Radioecology Applied to the Protection of Man and His Environment,* EUR 4800 d-f-i-e Luxembourg, May 1972.

7. R. S. Booth, S. V. Kaye, and P. S. Rohwer, "A Systems Analysis Methodology for Predicting Dose to Man from a Radioactively Contaminated Terrestrial Environment," Third National Symposium on Radioecology, May 10–12, 1971, Oak Ridge, Tennessee; proceedings will be published in USAEC CONF-710501.

8. R. S. Booth, S. V. Kaye, M. J. Kelly, and P. S. Rohwer, *A Compendium of Radionuclides Found in Liquid Effluents of Nuclear Power Stations,* ORNL-TM-3801 (in manuscript).

during the time period covered by the report. Meterological observations for each power station site, hydrologic dilution data, food-chain pathway modeling, and use and occupancy factors were used to predict the fraction of the released radioactivity expected to reach and expose man as a function of time and location. Factors for converting these predicted exposures to estimates of radiation dose to the exposed individual were obtained with our INREM internal dose code[9] and EXREM external dose code.[10] These individual dose estimates (rem) were combined with site-specific population data to estimate the population dose (man-rem) out to 50 miles from each power station. Participation in the in-depth technical analysis of radiological aspects of nuclear power stations and writing of environmental impact statements were valuable tests for the relevance of techniques and skills developed under the CUEX activity.

Estimation of the radiation dose to the biota is another area in which the Environmental Hazards Studies Group frequently has been asked to assist with environmental impact statement preparation. Organisms that live in the vicinity of a nuclear power station will be exposed to low levels of radioactivity in gaseous and liquid effluents. Attention was centered on the possible dose from liquid effluents, because some aquatic organisms concentrate radionuclides in their tissues to higher levels (bioaccumulation) than the concentrations of radionuclides in the ambient water. To facilitate estimation of the dose to the biota due to liquid effluents, an interactive computer code, BIORAD, was prepared for the PDP-10 computer. Details of the dosimetry considerations and assumptions in BIORAD and documentation of the bioaccumulation factors selected for use in the code are presented in a report currently being completed. Equilibrium is assumed to exist between all organisms and all radionuclides in the water in the vicinity of the nuclear power station. The BIORAD code is designed to provide dose estimates for aquatic plants, invertebrates, fish, waterfowl, and muskrats in the freshwater environment, and in the saline water environment, for algae, mollusks, crustaceans, fish, waterfowl, and shorebirds. The total dose estimate provided with BIORAD is the sum of the doses contributed from radionuclides assimilated from food and absorbed from water and contributed from immersion in water that contains the radioactive effluent. Possible dose contributions to the biota from gaseous effluents and from radionuclides accumulated in sediments were ignored, because no evidence existed that such doses would be more than a small fraction of the estimated internal dose that results due to bioaccumulation.

CHARACTERIZATION OF THE RADIOACTIVITY IN LIQUID EFFLUENTS FROM LIGHT-WATER POWER REACTORS

The radioactivity release experience of light-water power reactors has been analyzed in a number of ways to identify critical aquatic exposure pathways and critical radionuclides. The report describing this work[8] is, in effect, a collection in tabular form of various indexes of radiological impact which may be useful in assessing the environmental impact of radionuclides released from power reactors in their liquid effluents. Typical release rates under normal operation conditions (in curies per year) from both pressurized water reactors and boiling water reactors were tabulated. A concerted effort was made to derive numerical values from published measurements and experience, to ensure that these values were reasonably conservative, and to document these values with literature citations. Numerical values selected for environmental parameters are published values associated with operating power stations or power stations under construction. The radionuclides given consideration in this study are those which satisfied several criteria thought to be indicative of possible environmental impact (Table 9.1).

The radionuclides were ranked according to their potential dose to man for several environmental halftimes considering typical release rates from the reactor, radioactive half-lives, concentration factors from water to aquatic biota, typical dietary and recreational habits for man, and dose rate factors for ingestion and external exposure. Tabulations are included listing typical releases, bioaccumulation factors, dose rate factors, concentration in water that could result in a selected dose to man through selected exposure pathways, and concentrations in water that could result in a selected dose to the aquatic biota. Another index provided in the report,[8] the bioaccumulation factor from water to various aquatic organisms, indicates the importance of bioaccumulation for each radionuclide on the list in the assessment of its radiological impact. A tabulation of dose rate factors for man shows the

9. W. Doyle Turner, S. V. Kaye, and P. S. Rohwer, *EXREM and INREM Computer Codes for Estimating Radiation Doses to Populations from Construction of a Sea-Level Canal with Nuclear Explosives*, K-1752 (Sept. 16, 1968).

10. W. Doyle Turner, *The EXREM II Computer Code for Estimating External Doses to Populations from Construction of a Sea-Level Canal with Nuclear Explosives*, CTC-8 (July 21, 1969).

Table 9.1. List of radionuclides and decay chains that should be assessed in the liquid effluent of current light-water power reactors

^{3}H	^{90}Y	^{130}I
^{14}C	^{91}Sr-^{91m}Y-^{91}Y	^{131m}Te-^{131}Te-^{131}I
^{22}Na	^{91}Y	^{131}I
^{24}Na	^{93}Y	^{132}Te-^{132}I
^{32}P	^{95}Zr-^{95}Nb	^{133}I
^{35}S	^{95}Nb	^{134}Cs
^{46}Sc	^{97}Zr-^{97m}Nb-^{97}Nb	^{135}I
^{51}Cr	^{99}Mo-^{99m}Tc	^{136}Cs
^{54}Mn	^{103}Ru-^{103m}Rh	^{137}Cs-^{137m}Ba
^{55}Fe	^{105}Rh	^{140}Ba-^{140}La
^{59}Fe	^{106}Ru-^{106}Rh	^{140}La
^{57}Co	^{110m}Ag-^{110}Ag	^{141}Ce
^{58}Co	^{122}Sb	^{143}Ce-^{143}Pr
^{60}Co	^{124}Sb	^{143}Pr
^{63}Ni	^{125}Sn-^{125}Sb-^{125m}Te	^{144}Ce-^{144}Pr
^{64}Cu	^{125}Sb-^{125m}Te	^{147}Nd-^{147}Pm
^{65}Zn	^{125m}Te	^{147}Pm
^{69m}Zn-^{69}Zn	^{127}Sb-^{127m}Te-^{127}Te	^{182}Ta
^{86}Rb	^{127m}Te-^{127}Te	^{185}W
^{89}Sr	^{127}Te	^{187}W
^{90}Sr-^{90}Y	^{129m}Te-^{129}Te	^{239}Np

dose commitment to man per microcurie ingested or per unit concentration in the environment. A listing of the concentrations in water that deliver 500 millirems/year to standard man for each radionuclide and several exposure pathways may serve as a source of radiological significance indices and dose conversion factors.

DEVELOPMENT OF COMPUTER CAPABILITIES FOR ESTIMATING RADIATION DOSE

The INREM internal dose code[9] and the EXREM II external dose code[10] continue to be used regularly in our various dose estimation and dose assessment studies. Their use to provide dose conversion factors for the preparation of environmental impact statements is a typical example. Because of this continuing usage, both codes are being converted from their original form, which permits only batch operation on the IBM-360 computer, to a form that will permit their operation on the IBM-360 computer from Teletypes at remote terminals under the CRBE system. The conversion of these codes to CRBE facilitates machine storage of the massive data base of input information required for their operation. This further simplifies use of the codes and increases their convenience by reducing the amount of input required to operate them, and it also significantly reduces the probability of introducing errors when submitting problems to be run. The converted codes will output results in abbreviated form at the Teletype terminal or in the normal unabbreviated form on a line printer at the computing center. Conversion of EXREM II has been completed, and INREM is expected to be available in the converted form in the near future.

The number of inquiries concerning the INREM and EXREM II codes has increased, since they have been referenced frequently in the environmental impact statements prepared by ORNL. Because of these inquiries, both codes have been made available to the Radiation Shielding Information Center (RSIC) for inclusion in their computer code library. Copies of the codes with appropriate documentation will be provided by RSIC on request.

An interactive internal dose code, INDOS, has been written for the PDP-10 computer to supplement the INREM code. The INREM code was designed around Standard Man and the related dosimetry parameters found in ICRP publication 2.[11] The dose model used in INREM, a single exponential function to describe radionuclide retention in the reference organ, was developed to estimate dose for chronic low-level exposure of an average adult during a 50-year working lifetime. With INREM the user may obtain dose estimates for numerous reference organs simultaneously and total dose estimates for each of these organs from a mixture of radionuclides. The INDOS code, in contrast, is designed to estimate dose for a single radionuclide and a single reference organ. However, INDOS permits the user to select the radionuclide retention function; it may be (1) a single or multiple exponential function, (2) a power function, or (3) a mixed function combining 1 and 2. This flexibility allows the user to tailor his calculation either for a continuous exposure or for single or repeated short-term exposures whenever data availability permits. The INDOS code presently exists in two forms. The more general form, INDOS1, gives the user maximum flexibility, as he must supply all input parameters, select the reference organ, and specify the form of the retention. Output from INDOS1 is in tabular form, providing estimates of dose rate and dose as a function of time with tabular limits and increment specified by the user. The simplified form, INDOS2, requires the user to simply identify the radionuclide

11. International Commission on Radiological Protection, *Recommendations of the International Commission on Radiological Protection (Report of Committee 2 on Permissible Dose for Internal Radiation)*, ICRP Publication 2, Pergamon Press, London, 1959.

and quantify the radionuclide intake. The retention function, the reference organ, and the dosimetry parameters all have been preselected and are extracted from machine storage in INDOS2. Output of INDOS2 may be either tabular as described for INDOS1 or a Teletype graph of dose vs time, selected at the users option. Radionuclide intake for the codes may be specified in either of two ways: (1) discrete intakes, numbering not more than 50, or (2) a continuous intake at a constant rate. The INDOS code, particularly INDOS1, is viewed as a specialized tool to be used in applying state-of-the-art data and dose models to the critical radionuclide(s) in exposure situations of interest. Thorough testing and documentation of this code are incomplete. Because of its exploratory nature, modification and further development of INDOS can be anticipated.

RADIATION DOSES FROM HYPOTHETICAL EXPOSURES TO RULISON GAS

Doses have been estimated that people living in western Colorado communities might receive from hypothetical uses of gas from the Rulison well, the second natural gas well developed by underground use of a nuclear explosive, and a preliminary report of this work was published.[12] The results of this study have been reexamined and extended in preparation for publication in the open literature.

Production testing of the Rulison well[13] resulted in removal of most of the estimated 1300 Ci of tritium originally present in dry cavity gas. However, doses were estimated on the assumption that gas present in the cavity six months after detonation of the nuclear explosive was fed into the distribution system of the Rocky Mountain Natural Gas Company (RMNGC) for three years or of the Western Slope Gas Company, Rifle Division (WSGC), for one year at a rate of 1,000,000 ft^3 of dry, CO_2-free gas per day. This situation was designated case 1. In case 2, we estimated doses that might be received if the low-activity gas now present in the well were fed into the same gas systems at the same rate and under the same use conditions as in case 1.

The most significant results of this investigation are summarized in Table 9.2. The "ground-level" doses represent average annual whole-body doses that people served by each gas system might receive from inhalation and skin absorption of tritiated water vapor in the combustion products of gas hypothetically burned in homes and commercial establishments. The "industrial" doses are maximum doses that individuals might receive under the center line of plumes from the stacks of three plants. For the calculation of doses from the hypothetical use of nuclearly stimulated gas in unvented home appliances, we used United States average consumption

12. C. J. Barton, R. E. Moore, and S. R. Hanna, *Quarterly Progress Report on Radiological Safety of Peaceful Uses of Nuclear Explosives: Hypothetical Exposures to Rulison Gas*, ORNL-TM-3601 (October 1971).

13. Miles Reynolds, Jr., *Nucl. Technol.* 14, 187 (1972).

Table 9.2. Calculated whole-body doses from hypothetical exposure to Rulison gas combustion products

In millirems per year

Exposure source	Before flaring (case 1) First year	Second year	Third year	After flaring (case 2), first year
Ground level – RMNGC[a]	0.18	0.03	0.005	0.0001
Ground level – WSGC[b]	0.46			0.0003
Industrial – Rifle	0.24	0.03	0.004	0.0002
Industrial – Delta	0.10	0.01	0.002	0.0001
Industrial – Carbondale	0.02	0.002	0.0003	0.00001
Unvented range – RMNGC average	2.7	0.4	0.05	0.002
Unvented refrigerator – RMNGC average	2.6	0.4	0.04	0.002
Unvented range – Rifle	10			0.007
Unvented range – Grand Valley	18			0.013
Unvented refrigerator – Rifle	9			0.006
Unvented refrigerator – Grand Valley	18			0.013

[a]Rocky Mountin Natural Gas Company.
[b]Western Slope Gas Company, Rifle Division.

values[14] and assumed a ventilation rate of one air change per hour in a 1000-ft^2 house.

The effect of decreasing tritium concentration in the gas over the three-year period is clearly apparent in the case 1 doses. The estimated maximum doses from industrial sources that operate in three communities are comparable with the estimated average doses from ground-level sources, but both are about an order of magnitude smaller than the estimated home doses from unvented home appliances. The RMNGC system provides enough uncontaminated gas to give a reduction factor of about 0.10 for the radionuclide concentration in Rulison gas, while in the two communities served by WSGC, Rifle and Grand Valley, that are considered in this study, the reduction factors are 0.368 and 0.686 respectively. The difference in system dilution is reflected in the higher estimated doses in the WSGC communities shown in Table 9.2. The most highly exposed population group for the case 1 first-year situation would be those few inhabitants of Grand Valley who have both unvented ranges and refrigerators. This group, made up of fewer than five people, hypothetically could have received an annual whole-body dose of 36 millirems. The people in the larger population served by RMNGC who have both appliances might have received, on the average, 5.3 millirems.

Inspection of the last column in Table 9.2 shows that use of the gas presently in the well would result in estimated doses in the microrem range.

ECOFIT; A HYBRID COMPUTER PROGRAM FOR ITERATIVE FITTING OF ANALOG COMPUTER MODELS TO DIGITAL DATA AND PERFORMING ERROR PROPAGATION ANALYSIS

ECOFIT facilitates use of the Instrumentation and Controls Division's hybrid computer to rapidly and efficiently fit a model programmed on the analog computer to measured or expected system behavior represented as digital input. The analog computer solution to the model equations and the digital data are displayed simultaneously on separate channels of a four-channel 6 × 10 in. oscilloscope screen. Coefficient changes or patching changes associated with the analog model or selection of a different digital data set for display can be accomplished by the operator while the fit is progressing. The total time required for a change in a coefficient on the analog model to result in a corresponding change in the analog display takes only a fraction of a second. Thus the modeler sees on the oscilloscope screen a "movie" of his interactive, iterative fit. After the fit is accomplished, the modeler can direct ECOFIT to determine the uncertainty in the model predictions at selected times based upon uncertainties in the model parameters.

ECOFIT should be especially useful for ecosystem modeling, where systems are often qualitatively understood but the precise values for coefficients may not be known. The program would also be useful when not enough information is available to uniquely fit the analog model to the data or when the modeler desires to incorporate information into his fitting procedure which is difficult to program into an automated fitting procedure.

ECOFIT has been used in modeling the movement of tritium through fish (see "Applied Aquatic Studies," this report) and in investigating several models to simulate the movement of cesium through trees. The program was also used to determine the uncertainty in the predicted time behavior of tritium in the fish based upon uncertainties in the transfer coefficient used in the fish model.

DOSE ESTIMATIONS FOR THE HYPOTHETICAL USE OF NUCLEARLY STIMULATED NATURAL GAS IN THE CHEROKEE ELECTRIC GENERATING PLANT

One possible use of natural gas from nuclearly stimulated gas wells would be as fuel for electric generating plants. If the gas were actually used in such a plant, the gas combustion products discharged from its stack would contain small quantities of radionuclides and result in radiation exposures to people living in the area. The most important source of exposure would be inhalation and skin absorption of tritium in the form of tritiated water vapor (HTO).

The Cherokee power plant, a 710-MW steam electric generating plant located in the Denver area, was selected for a theoretical study of possible doses that people might receive in a realistic application. We assumed that 94×10^6 ft^3/day of gas containing 10 pCi/cm^3 of tritium was supplied to the plant from a well field. This quantity of gas would provide about half the gas required to operate the plant at capacity, or enough for three of the four boilers which discharge through two of the three stacks. The other boiler is assumed to burn either coal or uncontaminated gas.

The two stacks that would discharge the combustion products from nuclearly stimulated gas are both 300 ft

14. C. G. Segeler, ed., *Gas Engineers Handbook*, The Industrial Press, New York, 1966, p. 12/344.

in height and are separated by 220 ft. One stack would discharge the combustion products from burning 56.8 $\times 10^6$ ft^3/day. The rate of heat emission for this stack calculated from its stack gas temperature and the rate of discharge of combustion gases is 8.13×10^6 cal/sec. Corresponding values for the second stack are 37.2 $\times 10^6$ ft^3/day and 4.93×10^6 cal/sec.

The plant data given above and meterological data for the Denver area based on annual averages were used to estimate annual doses that might be received from exposure to the plumes of the plant. Plume rise was calculated from Briggs' equations.[15] Estimates of the ground-level tritium concentrations under the center line of the plumes were calculated from Pasquill's equation[16] as modified by Gifford.[17]

The predominant wind direction in the Denver area is toward the 22.5° sector due north. A computer program, STACKDOSE 2, a modification of a program previously described,[18] was used to estimate the highest tritium concentration and, hence, the highest dose and the distance from the plant in the predominant direction where this dose might be received. STACKDOSE 2 employs the equations referenced above and averages the tritium concentration over the 22.5° sector. Figure 9.1 is a plot of tritium concentration vs distance from the plant for wind direction toward due north (22.5° sector). The highest tritium concentration is 2.85×10^{-6} pCi/cm^3 at 23.5 km due north of the plant. This tritium concentration, when multiplied by 1872, a factor derived from the work of Cowser et al.,[19] gives a whole-body dose of 0.0053 millirem/year. Also shown in Fig. 9.1, for comparison, is a plot of the tritium concentrations for the direction toward due south (22.5° sector). The maximum concentration is closer to the plant in this direction, because the air is less stable when the wind blows toward the south in the Denver area than when the wind blows toward the north.

Program STACKMANREM was written to estimate the total dose to the population. Meterological data for 16 wind directions and the population distribution for the total population in the area (more than 1,400,000)

15. G. A. Briggs, *Plume Rise,* AEC Critical Review Series, TID-25075 (November 1969).

16. F. Pasquill, *Meteorol. Mag.* 90, 1063 (1961).

17. F. A. Gifford, Jr., *Nucl. Safety* 4(2), 47 (1962).

18. R. E. Moore and C. J. Barton, *Progress Report on Radiological Safety of Peaceful Uses of Nuclear Explosives: Preliminary Equations and Computer Techniques for Estimating and Controlling Doses from Nuclearly Stimulated Natural Gas,* ORNL-TM-3755 (June 1972).

19. K. E. Cowser et al., *Health Phys. Div. Annu. Progr. Rep. July 31, 1968,* ORNL-4316, p. 48.

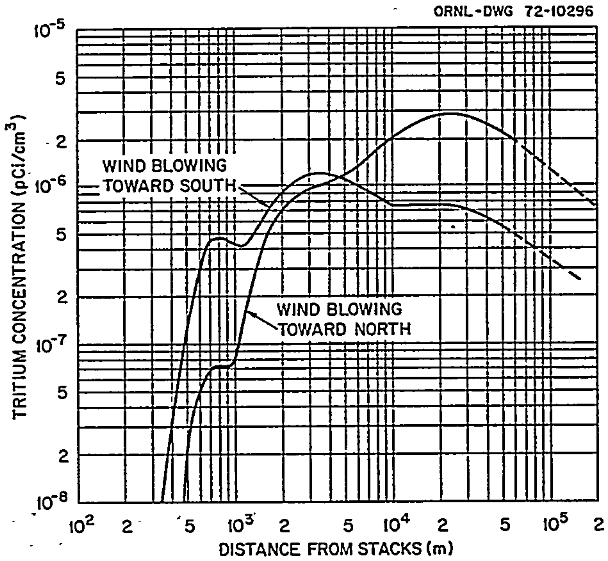

Fig. 9.1. Ground-level concentration of tritium discharged from Cherokee Plant burning gas containing 10 pCi/cm^3 of tritium.

were required as additional input data for the program, which gave a value of 2.05 man-rems/year. General north-south wind reversals occur in the Denver area almost daily, however, and result in additional exposures. Simple models were assumed for representing plumes blown back over the populated area after wind reversals occur. When these additional doses are added to those above, the highest potential dose to an individual is 0.007 millirem/year, and the estimated total population dose is 4.5 man-rems/year.

COMPUTER TECHNIQUES FOR ESTIMATING AND CONTROLLING TRITIUM DOSES FROM NUCLEARLY STIMULATED NATURAL GAS

Natural gas produced from fields of nuclearly stimulated gas wells will contain tritium and ^{85}Kr as well as small quantities of other radionuclides.[20] Tritium is present in the dry gas in tritiated hydrocarbons (CH_3T, C_2H_5T, etc.) and in hydrogen as HT.[20] The most important source of radiation exposure that could result from burning the gas in homes or in power plants is tritiated water vapor (HTO) in the gas combustion products.[21,22] Inhalation and skin absorption are the major potential exposure pathways that we have considered.[21,22]

20. C. F. Smith, *Nucl. Technol.* 15, 85 (1972).

21. C. J. Barton et al., *Nucl. Technol.* 11, 335 (1971).

22. D. G. Jacobs et al., *Health Phys.* 22, 429 (1972).

Doses received during hypothetical home use or by exposure to plumes from power plants could be controlled by scheduling the opening of gas wells in a well field so as to restrict the average tritium concentration in the gas flowing from the field to some maximum value. Two computer programs, WELLFIELD and WELLFIELD MAX, were written to aid in scheduling the opening of wells. Three programs were written for estimating doses from exposure to radionuclides released from stacks of power plants. Detailed descriptions of the programs discussed here, except for STACKMANREM, have been published.[18]

Program WELLFIELD computes daily tritium concentration, total gas flowed, and total tritium for 20 years in gas flowing from a gas field of as many as 30 wells in which each well is opened to a common pipeline at a different stated time. The input data required include the initial number of curies of tritium in the hydrocarbons and hydrogen in the chimney of each well and the initial volume of hydrocarbons and hydrogen in the chimney. Other data required are the time in days when each well is opened to the common pipeline, the flow rates of each well, and estimates of the parameter k as a function of time in days after each well is opened. The value of k is 1 − (volume of gas flowing into the chimney from the rock formation/volume of gas removed from the well).

Program WELLFIELD MAX computes the time in days for the most rapid opening of each well of a field of as many as 30 wells so that the average tritium concentration in the gas flowing from the field, when diluted with tritium-free gas to a stated flow rate, does not exceed a maximum stated value. The input data are the same as for WELLFIELD except for time in days when each well is opened, which WELLFIELD MAX determines. This program could be used in planning to control tritium concentrations in cases in which fixed quantities of gas must be supplied, as, for example, to fuel a power plant. Both WELLFIELD and WELLFIELD MAX can be easily expanded to include any desired number of wells.

Program STACKDOSE estimates the maximum annual whole-body tritium doses that any person might receive from exposure to the plumes of a power plant. The average tritium concentration in the gas, meterological data, and plant information, such as the stack heights, heat emission from each stack, and combustion rates, must be supplied to the program as input data. Program STACKMAX estimates the highest average tritium concentration that would be permitted in the gas so that no person could receive more than a specified annual dose. Program STACKMANREM, using the same input data as STACKDOSE as well as the population distribution in the area, estimates the total annual dose to the population in man-rems per year.

ESTIMATION OF THE CONTRIBUTION OF RADON IN NATURAL GAS TO NATURAL RADIATION DOSES IN HOMES

A literature survey[23] revealed that there is a considerable amount of published data on the radon content of natural gas at the wellhead but very little information on the concentration of this natural activity at points of use. It was also observed[23] that there are no published data on doses that people might receive from using radon-contaminated gas in unvented home appliances. It is desirable to compare doses that people would receive in this manner with estimated doses from man-made radionuclides introduced into nuclearly stimulated natural gas.

We have launched a three-part program to evaluate doses from this source of natural radioactivity in homes. The first part consists in gathering data on the radon concentration in gas going into several metropolitan areas. Two gas transmission companies supplying the New York City area are furnishing samples of their gas monthly for analysis by the New York Health and Safety Laboratory of the Atomic Energy Commission. One of the principal suppliers of the Chicago market is also taking two monthly samples for analysis at Argonne National Laboratory. Finally, the principal supplier of gas in Denver is sampling its two major gas sources each month, and the samples are analyzed at Colorado State University. This program will continue for a number of months to show whether seasonal variations in the radon content of the gas occur.

The second phase of this project is the calculation of radon daughter concentrations in a home atmosphere. Approximately 99% of the dose received from radon comes from its daughters. We concluded[21] that unvented gas ranges are the most probable source of radiation exposures from use of nuclearly stimulated natural gas in Colorado communities, and this is likely to be true in most other locations in the United States as well, because use of unvented gas heaters is generally illegal. Since gas ranges are used intermittently, it is necessary to calculate both the rate of buildup of the radon daughters in the home while the range is used and

23. C. J. Barton, *Radon in Air, Natural Gas, and Homes: A Preliminary Literature Survey and Evaluation,* ORNL-CF-71-5-48 (May 1971).

their rate of disappearance between meals as a function of injection rate and home ventilation rate. A computer program was written to handle this complex situation, and calculations were performed using a radon concentration of 1 pCi/liter and home ventilation rates ranging from 0.5 to 6 air changes per hour. The program calculates numbers of atoms of each of the first four daughter products in the home at 60-sec intervals to 30,000 sec ($8\frac{1}{3}$ hr). It also gives values for the cumulative average from the beginning of gas use or from the end of use during between-meal periods. This phase of the investigation is essentially completed.

The final phase of the study, which has received only preliminary consideration, is the estimation of radon daughter doses resulting from typical radon concentrations in home gas use situations. Because of the scarcity of definitive data on the size of particles to which radon daughter atoms or ions become attached and the resultant deposition pattern in the human respiratory system, it will be difficult to avoid uncertainty in converting radon daughter concentrations in the home into potential doses. Our efforts in this area will be devoted to minimizing the uncertainty by making use of the best available published data.

THE RELATIVE RISKS FROM RADIONUCLIDES FOUND IN NUCLEARLY STIMULATED NATURAL GAS[24]

When radionuclides are present in gas from nuclearly stimulated wells, there are numerous pathways through which these nuclides may cause radiation exposure to man. Since millions of people could potentially be users of gas produced by nuclear gas stimulation technology, caution must be exercised in establishing acceptable concentrations of man-made radioactivity in natural gas for industrial and domestic consumption.

Only two gas-stimulation experiments have been completed (Gasbuggy and Rulison), and two more are planned (Rio Blanco and Wagon Wheel). Radionuclides found in the completed experiments were ^{85}Kr, ^{3}H, ^{37}Ar, ^{39}Ar, ^{14}C, and ^{203}Hg. Other radionuclides were below detection limits when Gasbuggy gas was tested by Smith.[25] The small number of radionuclides found is not too surprising when one considers that the explosives are detonated in an atmosphere of water and hydrocarbons where most of the fission and activation products would be expected to exist as metals or metal oxides. The principal exceptions are the rare gases, iodine, carbon, and tritium. Since a minimum of 90 days will occur before gas would be produced from a stimulated well, radioactive decay eliminates all of the short-lived volatile isotopes which otherwise would have been detected.

Of the radionuclides found in nuclearly stimulated gas, ^{85}Kr, ^{3}H, ^{14}C, and ^{39}Ar contribute over 99.9% of the potential dose at radionuclide concentrations observed or expected. It appears unlikely that other radionuclides will become significant, but each geological formation of interest, as well as device components, must be analyzed with respect to this possibility. For dose estimation, ^{39}Ar is similar to ^{85}Kr, and they may be considered together. On this basis we have estimated the relative percentage of somatic dose from these radionuclides as shown in Table 9.3. The concentrations shown in column 3 are based on estimated first-year gas production from a nuclearly stimulated well as described by Rubin[26] and literature values for yield and dose conversion factors for each radionuclide.

The fact that tritium and ^{85}Kr will exist in the gas at concentrations many times the maximum permissible concentration in air is cause for concern and must be considered. We feel that a reasonable maximum permissible concentration in gas might be based on the lower explosive limit of 5% natural gas in air. Applied to the present maximum permissible concentration in air of 0.2 pCi/cc for tritium oxide, this yields a maximum ^{3}H concentration in gas of 4 pCi/cc (STP). On this basis, first-year nuclearly stimulated gas would still have to be mixed with uncontaminated gas, but large amounts could be distributed through existing pipelines supplemental to present production as it declines. At projected production rates,[26] gas from nuclearly stimulated wells is essentially uncontaminated after the first year of production.

Using 4 pCi/cc (STP) as the allowable maximum for tritium in natural gas and other radionuclide concentrations as shown in column 1 of Table 9.3, we can estimate the maximum dose to an individual resulting from unvented combustion of gas for heating or cooking based on air saturated with combustion-produced moisture at 80°F, 365 days per year. This condition can only be realized in extremely cold climates and should be considered calculable but totally

24. Abstracted from a paper of the same title prepared for the Third International Atomic Energy Agency Peaceful Nuclear Explosives Panel, Vienna, Austria, November 26–30, 1972.

25. C. F. Smith, *Project Gasbuggy Gas Quality Analysis and Evaluation Program, Tabulation of Radiochemical and Chemical Analytical Results,* USAEC report UCRL-50625, Rev. 2 (April 1971).

26. B. Rubin et al., *An Analysis of Gas Stimulation Using Nuclear Explosives,* USAEC report UCRL-51226 (May 1972).

Table 9.3. Relative percentage of total estimated somatic dose from radionuclides in nuclearly stimulated gas

Radionuclide	Assumed maximum permissible concentration in gas (pCi/cc)	Percentage of total estimated dose	Average concentration first-year production (pCi/cc)	Fraction of maximum permissible concentration in air
^{3}H	4	69	<20	<100
^{85}Kr	13	26	65	217
^{14}C	0.20	<5	<1	<10
All others		<1		

unlikely. The permissible dose limit for an individual member of the general public (500 millirems/year) would not be exceeded even for these conditions. We estimate less than 103 millirems/year to the whole body and 163 millirems/year to the shallowest layer of live skin.

An extensive theoretical study of the impact of the use of nuclearly stimulated gas in the Pacific Southwest[27] has been completed. Based on conservative assumptions, the average dose to the population exposed would be less than 1.25 millirems/year from all gas used in the Los Angeles Basin if all household appliances are vented except those used for cooking. At this level of average dose, we compare in Table 9.4 the death rate estimated for the use of nuclearly stimulated gas with similar estimates for other sources of radiation exposure of the public, as well as the death rates associated with other risks encountered in the normal activities of everyday life in the United States of America.[28] The intent is to give perspective and not to minimize the significance of the potential dose to man from the use of nuclearly stimulated natural gas. Even though this risk may be small in comparison to some other risks, all radiation exposure should be kept "as low as practicable." The use of nuclearly stimulated gas as assumed in this theoretical analysis would result, in our opinion, in an acceptably low risk. This opinion is subjective; however, the more important objective is to supply a basis for rational judgment from which the radiation risk can be assessed as an integral part of the cost-benefit analysis of nuclear gas stimulation technology.

27. D. G. Jacobs et al., *Theoretical Evaluation of Consumer Products from Project Gasbuggy, Final Report, Phase II: Hypothetical Population outside San Juan Basin,* USAEC report ORNL-4748 (February 1972).

28. *Accident Facts,* National Safety Council, Chicago, Illinois, 1971 ed.

Table 9.4. Comparison of estimated deaths in the United States population due to natural background and man-made radiation with deaths due to other causes

Cause of death	Number of deaths	Rate[a]
All causes	1,930,082	9660
Heart disease	744,658	3730
Cancer	318,547	1590
Stroke	211,390	1060
Accidents	114,864	570
Pneumonia	66,430	330
Diabetes mellitus	38,352	190
Arteriosclerosis	33,568	170
Natural background radiation[b]	3,400	17
Man-made sources of radiation		
Medical diagnostic x-rays	4,000	20
Fallout from nuclear weapons	80	0.4
Consumer devices	80	0.4
Nuclearly stimulated natural gas		0.2
Industrial uses of radiation	<40	<0.2
Power reactors	<40	<0.2

[a]Deaths per million population.
[b]0.1 rem/year.

DEVELOPMENT OF SAMPLING AND ANALYTICAL TECHNIQUES TO MEASURE AIR CIRCULATION AND RESIDENCE TIMES IN HOMES

Both the credibility and accuracy of our population dose assessment for the hypothetical use of nuclearly stimulated gas are dependent on the precision with which the various parameters used in the dose estimates are known. The parameters to calculate dose from a known radionuclide concentration in air are well established for the major contaminants in the gas.

Many statistics exist on gas usage in homes as well as data on size and construction of homes, but very few data are available on air circulation and residence time in dwelling units.

For our population dose assessment we have used one air change per hour and uniform dispersal of the gas combustion products throughout the dwelling unit. The validity of this assumption is not known, although it is believed to be reasonably conservative. In order to substantiate this assumption, we have adapted the method used by Drivas[29] so that we may obtain data on dwelling units.

We propose to release approximately 30 cc (STP) of sulfur hexafluoride per 1000 ft^3 of dwelling volume and to serially sample various locations within the dwelling by squeeze-pumping 50-cc polyethylene bottles. After each sample is taken, the bottles will be capped with a cap containing a rubber septum. The samples will then be returned to ORNL for analysis.

Sulfur hexafluoride has been shown to be completely nontoxic[30] by exposing white rats for a 24-hr period to an atmosphere of 80% SF_6 and 20% O_2. The conclusion was that sulfur hexafluoride should be considered pharmacologically inert in animals and man.

For analysis, 0.1 to 1 cc of the sampled air is withdrawn through the septum by a hypodermic needle and injected into a Hewlett Packard 7620A gas chromatograph using 90% Ar–10% CH_4 as the carrier gas. The SF_6 is separated at 60°C on a $\frac{1}{8}$-in.-OD, 4-ft-long column packed with 5-A molecular sieves. Because the SF_6 is too large to enter the sieve pores, it is not significantly absorbed and is the first observable constituent reaching the electron capture detector, followed by oxygen and nitrogen. Elution is complete within about 5 min; so large groups of samples can be run quickly. In practice, the ratio of the SF_6 peak to the N_2 peak is used in determining the concentration of SF_6 from the calibration curve shown in Fig. 9.2.

It is expected that the application of this technique to residential measurements will begin in the near future.

TRITIUM BEHAVIOR IN A NATURAL GAS PROCESSING PLANT

A final report was completed and issued on an experiment involving 40,000 ft^3 of Gasbuggy gas containing 12.5 mCi of tritium mixed with 1,800,000 ft^3 of nonradioactive field gas and processed through a small natural gas plant over a 12-hr period.[31] The tritium activity in the diluted gas entering the plant and in the output gas was measured with on-line monitors. Samples of gas and liquid plant products were taken periodically and later analyzed. Additional tritium (about 70 mCi) was added to the plant fuel gas to raise the tritium levels in the area atmosphere to levels expected from processing gas from a nuclearly stimulated gas field.

29. Peter J. Drivas et al., "Experimental Characterization of Ventilation Systems in Buildings," *Environ. Sci. Technol.*, July 1972.

30. David Lester and Leon A. Greenberg, *Arch. Ind. Hyg. Occup. Med.* 2, 348–49 (1950).

31. M. J. Kelly, C. J. Barton, A. S. Meyer, E. W. Chew, and C. R. Bowman, *Theoretical Evaluation of Consumer Products from Project Gasbuggy – Final Report: Tritium Behavior in a Natural Gas Processing Plant*, ORNL-4775 (July 1972).

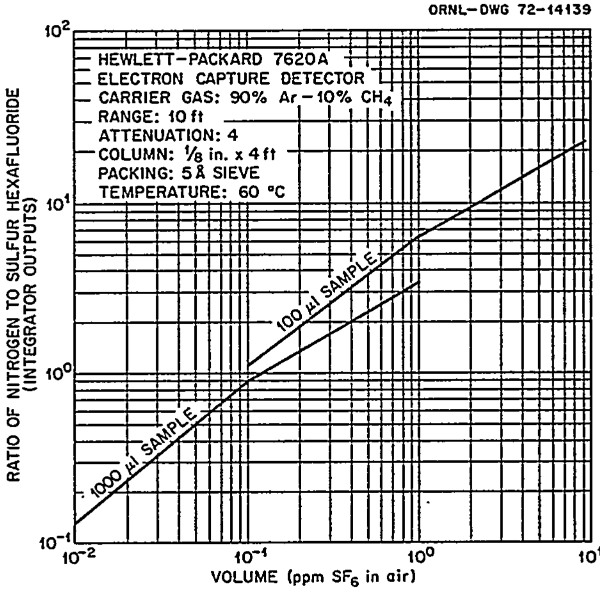

Fig. 9.2. Calibration curve for the detection of sulfur hexafluoride in air by electron capture gas chromatography.

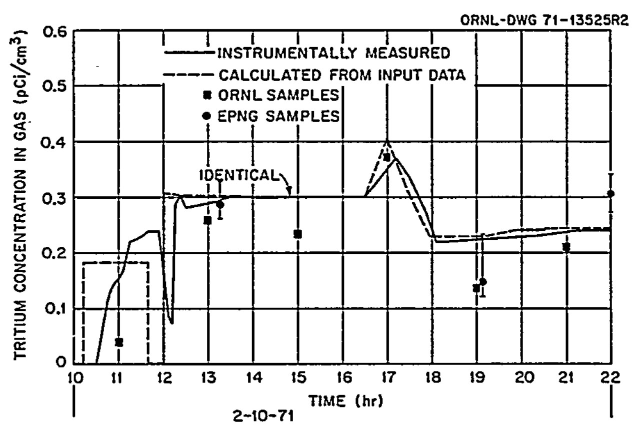

Fig. 9.3. Concentration of tritium in output gas at the reprocessing plant.

The observed tritium distribution among plant products followed the pattern predicted by pretest calculations. There was no evidence of isotopic exchange that would cause a buildup of tritium in the oil used in absorption recovery of liquefied petroleum gas and natural gasoline. Analysis of area moisture samples showed a maximum HTO concentration of 131 pCi/m^3, corresponding to a whole-body dose of 0.06 millirem per working year (2000 hr).

The test results suggest that processing of gas from nuclearly stimulated wells will result in doses less than 1% of natural background to plant operating personnel and no other operating problems.

This test also provided an opportunity to test the performance under field conditions of an on-line monitor for tritium and krypton built by the Eberline Instrument Corporation for the El Paso Natural Gas Company (EPNG). Figure 9.3 shows a comparison between the on-line data, grab sample data, and expected values calculated from plant input data. The comparison between the calculated values and on-line measurements is very good. More variation in the activity of the grab samples may be expected than that shown by the on-line monitor, which is by necessity an averaging device with some time lag. These data indicate that on-line monitoring and control of pipelines containing nuclearly stimulated gas, as would be required for compliance with licensing regulations, is practical.

10. Thermal Effects

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SCOPE

The objective of the Thermal Effects program is to develop information that has predictive utility for assessing impacts of thermal discharges on aquatic life. Information sought ranges from the level of physiological effects on single organisms to the level of dynamic aquatic communities which may interact with cooling waters of power plants. The program encompasses both a search for fundamental (and yet unknown) temperature limitations of aquatic organisms and the production of data on well-understood responses such as thermal tolerance and growth, for which data are needed on additional species. There is direct interchange of data and research needs between this research program and the Laboratory's environmental impact statement activities.

ANNUAL REVIEW OF THERMAL EFFECTS LITERATURE

The thermal effects literature of 1971 was reviewed, and two documents were published. One, largely in narrative form, was published as part of the review of the literature of 1971 on waste water and water pollution control by the *Journal of the Water Pollution Control Federation.* The June issue of the journal is devoted to comprehensive reviews of the water pollution control literature for the previous calendar year. The second publication was issued by ORNL through the Environmental Information Systems Office. It reproduced the bibliographic information on the 1971 thermal literature that has been stored in the ORNL computer files, and it contained a KWIC (Key Word in Context) index of titles, an author index, a key-word index (for key words not in titles), and a taxonomic index. The second document was necessitated by lack of indexing in the journal version, and it serves as an example of the capabilities of the ORNL information system.

The 1971 thermal review covered 394 references. These included topical categories, including reviews, site studies, producers, reproduction, development, morphology, distribution, thermal tolerance, physiology of cold shock, tissue and organ responses, growth, food transport, digestion, absorption of food, temperature-salinity interactions, radionuclide uptake, combined stresses, feeding rates, preferred temperature, avoidance, orientation, activity, predator-prey relations, decomposers, disease, and beneficial uses.

EFFECT OF COLD SHOCK ON SUSCEPTIBILITY OF JUVENILE FISHES TO PREDATION

Juvenile channel catfish (*Ictalurus punctatus*) and largemouth bass (*Micropterus salmoides*) were found to be selectively preyed upon when given acute thermal

1. NSF–Undergraduate Research Participant.
2. Dual capacity.
3. Ecological Sciences Information Center.
4. Instrumentation and Controls Division.
5. Graduate student, University of Tennessee.

cold shocks in excess of about 5 to 6°C and then offered to predators simultaneously with unshocked fish (Fig. 10.1). Smaller cold shocks between 0 and 5 to 6°C caused the fish to be less susceptible. The cold-shock experiments were conducted to provide guidance for shutdown of nuclear power plants returning thermal effluents to natural waters. Criteria are needed in order to minimize detrimental effects to important aquatic organisms which become acclimated to increased water temperatures resulting from the effluents.

Experiments on relative vulnerability of shocked and unshocked fish to predation were conducted as follows. Groups of young fish were held for three weeks or longer in a range of water temperatures above that of ambient springwater supplied to the laboratory (which was 16 or 17°C at the time of the experiments). Holding for this length of time is generally sufficient to cause metabolic acclimation. Other fish from the same stock were held at the ambient springwater temperature. Equal numbers of warm-acclimated and cool-acclimated fish were then offered simultaneously to adult largemouth bass predators in a large fish tank which was devoid of shelter for the young fish. The prey groups were differentially marked with cold brands. Predation was stopped when half of the prey had been eaten. The survivors were tallied, and the "predation ratio" (percent shocked fish eaten/percent unshocked fish eaten) was calculated. There are other ways to express the results, some involving calculating theoretical instantaneous rates of predation, but the simpler calculation yields the same conclusions.

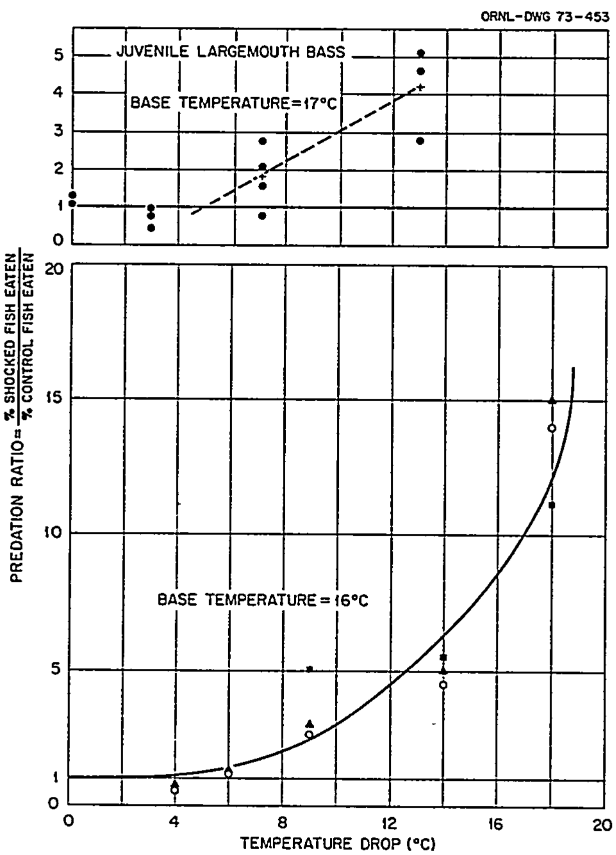

Fig. 10.1. Differential predation of adult largemouth bass on cold-shocked and unshocked juvenile fishes (largemouth bass and channel catfish). A "predation ratio" of 1 indicates no difference in susceptibility between shocked and unshocked groups; a ratio greater than 1 indicates the shocked fish were more susceptible; a ratio less than 1 indicates the unshocked fish were more susceptible. The lines merely indicate trends in data.

These results suggest that there may be abnormally high losses of young catfish and bass should thermal discharges exceeding 5 to 6°C above ambient suddenly cool. The losses would be incurred by abnormally high rates of predation upon the stressed fish as they disperse from the previously heated zone. These deaths would not be recognized as a fish kill, yet populations may still be depleted to unacceptable levels. The similarity of results for two species may suggest a general biological stress response that is not species specific. Further studies with other species and with different base (cool) temperatures are under way.

EFFECTS OF TEMPERATURE AND OTHER ENVIRONMENTAL FACTORS ON THE GROWTH AND DEVELOPMENT OF *MYRIOPHYLLUM SPICATUM* L.

The submerged aquatic weed *Myriophyllum spicatum* L. (Eurasian water milfoil) was studied to investigate the effects of various environmental conditions, particularly temperature, on growth and development, using field analyses of infested areas of the Melton Hill Reservoir and related laboratory experiments.

In six heavily infested areas located in various temperature regimes of the reservoir, both upstream and downstream from the thermal discharge canal of the Bull Run Steam Plant, milfoil stands were sampled monthly between August and November, and physical and chemical parameters were monitored and evaluated to determine the relationship of standing crop to temperature and other factors. Light penetration as a function of water depth and turbidity appears to be the primary factor controlling the distribution of *M. spicatum* in Melton Hill Reservoir. The dense growth of milfoil stands in gravel, sand, and silt substrates throughout the reservoir suggests that distribution is not significantly limited by sediment size or type.

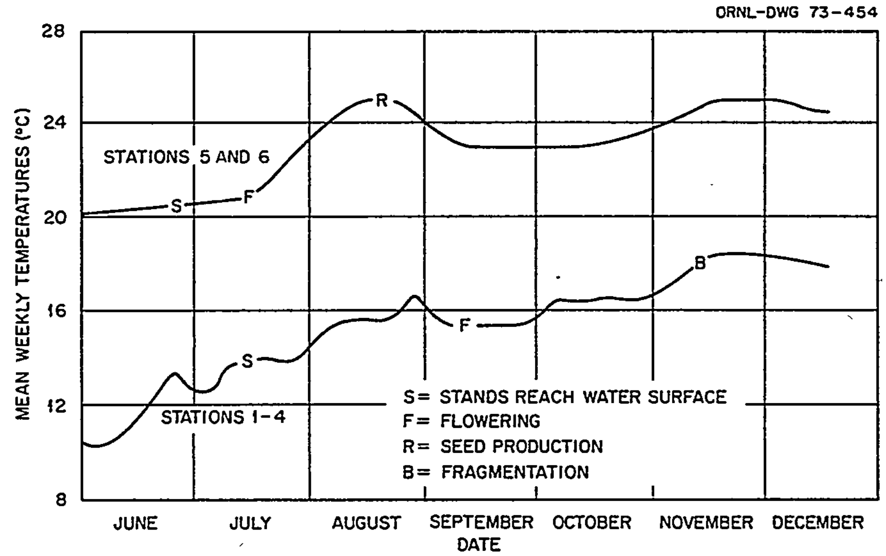

Fig. 10.2. Effect of temperature on the phenology of *M. spicatum*.

Standing-crop estimates, plant tissue analysis of mineral content, field observations, and laboratory studies showed that, while reservoir temperatures do not limit the distribution of *M. spicatum,* they influence the metabolism, vegetative reproduction, fruit development, and abundance of the plant. Warm temperatures between 23 and 27°C increase rates of phenological development, as shown in Fig. 10.2. Plant stands in warm temperatures at sampling stations 5 and 6 reached the water surface in June and flowered in July; stands in cool water temperatures at stations 1–4 reached the surface one month later, flowering in September. Seed development occurred only at stations 5 and 6 in surface-water temperatures greater than 24°C during August, September, and October. Fall fragmentation occurred in mid-November at stations 1–4 and in late December at stations 5 and 6. Maximum standing-crop and flower production occurred at stations 5 and 6 during all sampling periods. There appears to be a direct relationship between temperature stability and plant density, with standing crop increasing as daily temperature fluctuations decrease. Upstream stations 1–4, with radical rates and magnitudes of temperature fluctuation, exhibited the lowest standing crops, while maximum standing crops occurred at stations 5 and 6, where daily temperatures were nearly constant within any given period of time. This may imply that magnitudes and rates of temperature fluctuation exert more influence on plant growth than does the single factor of temperature range or mean for any period of time.

Increase in temperature from 11 to 26°C greatly increases the rates and amounts of nutrient absorption and translocation in *M. spicatum,* as indicated by uptake experiments with radioisotopes of phosphorus and potassium.

TEMPERATURE AND FISH GROWTH

Annual Growth Patterns in an Unexploited Largemouth Bass Population in a Large Cooling Reservoir

There are few available field data which can be used to evaluate the effects of thermal discharges on growth patterns of largemouth bass populations. Data obtained during most field studies at power plants are commonly inadequate for proper interpretation. Because bass and other game fish are attracted to the warmer water of the plume, fishing intensity commonly is greater in these areas. As a result, populations around power plant discharges can be largely composed of immigrants instead of residents. This source of sampling bias severely restricts the utility of data from sampling near power plant discharges.

Because of these limitations, an unfished population was studied in Par Pond, a 1120-ha cooling pond on the Atomic Energy Commission's Savannah River Plant near Aiken, South Carolina. Bass were collected at various times and various locations in the pond over a period of two years. The body temperature, length, and weight of each fish were recorded. Fish caught in the winter were in better condition than those taken in the summer and averaged about 35% heavier for the same length. During the summer, bass taken near the discharge averaged 25% lighter than those taken from the opposite end of the lake.

Weight Losses of Unfed Largemouth Bass

In order to understand how temperature is related to changes in fish population biomass, it is necessary to know how temperature affects both food conversion and weight loss during periods of starvation. In present investigations, 65 largemouth bass ranging from 20 to 100 g were held indoors at 15, 20, 25, 28, or 30°C and weighed over three weekly intervals. Preliminary analysis shows that the weekly weight loss of individual fish remained nearly constant, while weight loss varied a great deal between fish. Within treatments, over 90% of the variability was found to be linearly related to fish size. However, differences between treatment were also apparent such that higher temperatures were associated with greater average weekly weight reductions.

Laboratory Studies of Channel Catfish Growth

Weights of juvenile channel catfish (*Ictalurus punctatus*) initially averaging about 7 g were determined weekly for 17 weeks in groups held at 25, 30, and 35°C. Food was provided in excess. Growth was most rapid at 30°C. For the first 80 days there was little difference in growth between the 25 and 35°C groups, each growing to an average of about 12 g. Thereafter, the 25°C group grew rapidly, while there was no growth by the group at 35°C. These results suggest an age-specific pattern of growth response to temperature. The temperature of zero growth for juvenile channel catfish appears to be very near 35°C.

EFFECTS OF ACUTE THERMAL SHOCK ON CARP EGGS

The effects of an acute thermal shock on the development and hatchability of *Cyprinus carpio* eggs were investigated by culturing eggs at 25°C and subjecting them to a 10-min thermal shock at different stages of development. Eggs were shocked at 35, 37½, 40, 42½, and 45°C and then immersed in water at a temperature midway between the respective treatment temperature and 25°C. Final cooling to 25°C was by convection in an environmental chamber.

The maximum temperature that eggs survived was 40°C; however, as Fig. 10.3 shows, the survival of eggs exposed to 37½ and 40°C depended on the stage of development at the time of the shock. There were two particularly sensitive periods: the first 6 hr of development when eggs were in the cleavage stage, and between 12 and 17 hr after fertilization when organogenesis was just beginning. Thermal resistance was highest during gastrulation and the latter stages of development.

Although the hatchability of carp eggs was not affected by a 35°C shock, there was a high frequency of

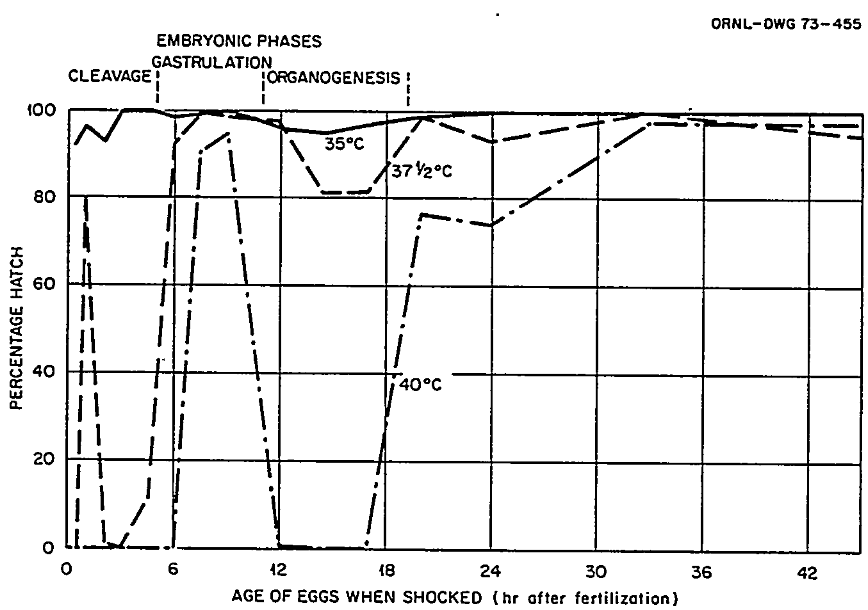

Fig. 10.3. Effects of an acute thermal shock on the hatchability of carp eggs. Percentage of eggs that hatched following a 10-min thermal shock at temperatures of 35, 37½, and 40°C at different stages of development.

abnormal larvae when eggs were shocked at 35°C during the first 3 hr of development. Forty-five percent of the eggs exposed to 35°C 2 hr after fertilization produced abnormal larvae. The frequency of abnormal larvae was usually higher in eggs exposed to 37½ and 40°C than in controls during periods when egg hatchability was poor.

Eight-day-old larvae were subjected to a 10-min thermal shock at temperatures of 33, 35, 37, 38½, and 40°C. Temperatures of 33 and 35°C did not have a permanent effect on the larvae, but all larvae exposed to 37°C or more died within an hour after being shocked.

ACOUSTIC TEMPERATURE TELEMETRY FROM FREE-SWIMMING FISH

A temperature-sensitive implantable fish tag has been developed, with the thermistor located at the end of a flexible appendage (Fig. 10.4). The thermistor can be implanted with the transmitter to measure fish body temperature or brought outside the fish to measure water temperature. The tags transmit acoustic energy at frequencies between 65 and 100 kHz and are pulse-period modulated by a single capacitor complementary multivibrator which is well compensated for changes in battery voltage. The use of a breadboard-type monolithic integrated circuit allows considerable circuit sophistication in a small space and aids in reducing assembly cost. The entire assembly is covered with silicone rubber to ensure biological compatibility, and the battery is easily replaceable. When equipped with a two-cell battery, the useful life is four months and the effective range for temperature telemetry extends to 500 yd. Signals with diminished quality can be received at greater distances and are useful for locating fish in the field. The calibration accuracy is within ±0.2°C over a +5 to +35°C range and is maintained throughout the battery life. The overall dimensions of 32 × 17 mm (for a two-cell battery excluding thermistor) make the tag suitable for use in fish as small as 1 lb. The received signal is easily decoded using commercially available gear by interfacing the receiver output with a frequency counter to measure the pulse period. Provisions are included for storing the pulse periods on punched paper tape for later conversion to temperature by a digital computer.

The fish tag has proved useful for determining the rates of change of internal fish body temperatures following water temperature changes. The fish remain unrestrained during temperature equilibration, and thus equilibration time reflects heating or cooling effects of activity patterns. Largemouth bass in the 2- to 3-kg size range required about 30 min for the coelomic region behind the heart to reach 90% of the new temperature, regardless of the temperature increment (increases and decreases were tested from 2 to 10°C). Temperatures changed more rapidly in smaller fish. Heating and cooling followed an exponential model, with a lag period of approximately 4 min. These experiments assist in evaluating the reliability of fish body temperature measurements taken in the field as indicators of habitat temperature.

In a cooperative effort with the Savannah River Ecology Laboratory and the Fishery Cooperative of the University of Georgia, these tags are being used to study the behavior of largemouth bass in two reservoirs receiving thermal effluents. In the larger reservoir, where a well-defined thermal plume exists, preliminary summer results show that the bass do not remain constantly in the warmer water but tend to wander wildly with frequent returns to the plume. In the smaller of the two reservoirs, tagged bass were traced to previously unknown cool areas which provided them refuge from the heated water.

EFFECT OF TEMPERATURE ON RATE OF FOOD CONSUMPTION AND PHOSPHORUS TURNOVER IN A BENTHIC INVERTEBRATE

Aquatic consumers can be considered element pools that are in a time-dependent steady state (i.e., the rate of change in the element pool equals the rate of input minus the rate of loss). Temperature is an important controlling variable of the metabolic processes which affect the rates of elemental input and loss. The effect of temperature on the phosphorus budget of *Goniobasis clavaeformis*, an operculate snail which grazes on aufwuchs in streams, was studied under laboratory conditions using radioactive phosphorus. The food ingestion rate and retention, absorption efficiency, and equilibrium body load of phosphorus in this species were determined at various temperatures and the data analyzed using an elemental absorption and retention model for ingested materials.[6] Snails at four different temperatures (10, 13.8, 15, and 19.3°C) were allowed to feed on aufwuchs labeled with ^{32}P for 30 min, and the retention of ^{32}P at the four temperatures was determined thereafter.

The average food ingestion rate of *Goniobasis* first increased with increasing temperature and then decreased at temperatures greater than 14°C.

6. R. A. Goldstein and J. W. Elwood, "A Two-Compartment, Three-Parameter Model for the Absorption and Retention of Ingested Elements by Animals," *Ecology* 52, 935–39 (1971).

Fig. 10.4. Prototype model of temperature-sensing ultrasonic fish tag.

An empirical temperature-ingestion rate function was fitted to the experimentally measured values by means of nonlinear least squares,

$$i(T) = d_1 + d_2 \times (T - 10) \times e^{\gamma(T-10)} , \tag{1}$$

where $i(T)$ is the food ingestion rate of *Goniobasis* in milligrams of ash-free dry weight (AFDW) snail^{-1} hr^{-1}; d_1, d_2, and γ are empirical constants; and T is water temperature in degrees centigrade. The general pattern of food ingestion rate in *Goniobasis* as a function of temperature is characteristic of that found for other aquatic consumers including zooplankton and fish.

A retention function of ^{32}P was fitted to the retention data for snails at each of the four temperatures by means of nonlinear least squares,

$$R(t) = a_1 e^{-\alpha_1 t} + a_2 e^{-\alpha_2 t} , \tag{2}$$

where R is the percent of ^{32}P retained at time t, and α_1 and α_2 are transfer functions for the processes of elimination of unabsorbed and elimination of absorbed ^{32}P respectively. The elimination rate of absorbed ^{32}P (and stable phosphorus) increased with temperature over the entire range of experimental temperatures. An Arrhenius temperature relationship,

$$k_2(T) = be^{-\beta/(T+273)} , \tag{3}$$

where k_2 is the elimination coefficient of absorbed ^{32}P, T is temperature in degrees centigrade, and b and β are empirical constants, was fitted to the calculated elimination coefficients of absorbed ^{32}P by means of nonlinear least squares. The Arrhenius temperature relationship has been found useful in explaining the temperature dependence of biological rates, and β can be theoretically identified with a conceptual activation energy for particular chemical reactions of biological processes.

At equilibrium the rate of change in the amount of ^{32}P in the snail is 0 (i.e., input equals loss). If snails are allowed to feed continuously on labeled aufwuchs, the amount of ^{32}P will eventually reach an equilibrium which can be computed as

$$B_e(T) = \frac{i(T)\, \mu(T)}{k_2(T) \cdot [\mu(T) + k_1(T)]} , \tag{4}$$

where B_e is the equilibrium body load of ^{32}P in the snail, i is the ingestion rate of ^{32}P, μ is the absorption coefficient of ^{32}P from the gut, k_1 and k_2 are coefficients for the processes of elimination of unabsorbed and elimination of absorbed ^{32}P, respectively, and T is temperature in degrees centigrade. The equilibrium body load of phosphorus for each temperature was calculated with Eq. (4) by using the mean concentration of stable phosphorus in the aufwuchs and assuming that the values of k_1, k_2, and μ for stable phosphorus are the same as those for radioactive phosphorus. Figure 10.5 shows the calculated values of B_e at the various temperatures and a curve which represents the substitution of the fitted functions in Eq. (4). These data thus show that the equilibrium body load of phosphorus in *Goniobasis* first increases with temperature, reaches a maximum between 11 and 12°C, and then decreases at temperatures greater than 12°C. Since these organisms are exposed to temperatures between 10 and 20°C during the year, the equilibrium phosphorus load presumably also changes unless the phosphorus concentration in their food supply increases. Continual exposure to elevated temperatures would presumably reduce the phosphorus load, which would eventually stress the organism if levels were reduced sufficiently to cause a mineral imbalance in the body.

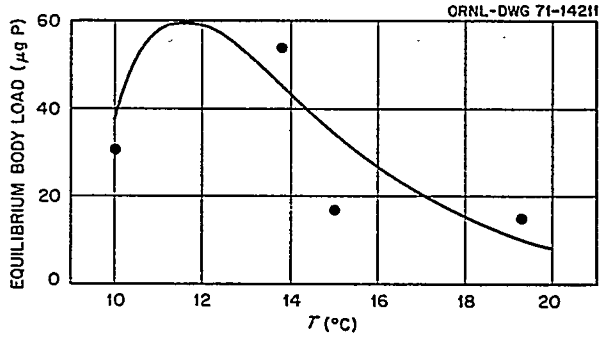

Fig. 10.5. Calculated equilibrium body load of phosphorus (B_e) in *Goniobasis clavaeformis* at various temperatures and curve of the estimated equilibrium body load generated by substituting the fitted functions into Eq. (4).

For toxic elements (e.g., heavy metals) and radionuclides which behave physiologically the same as phosphorus in terms of uptake and retention, the lower equilibrium body load at higher temperatures would be an important factor in reducing their effects on species that are chronically exposed to these materials.

POPULATION DYNAMICS OF STRIPED BASS, *MORONE SAXATILIS*

To assess the probable importance of mortality resulting from entrainment of striped bass eggs and larvae, an analysis of information in the literature was conducted to identify those factors which are presently regulating the numerical abundance and biomass of populations of striped bass. Particular emphasis was placed on evaluation of possible density-dependent relationships that might compensate for increased mortality of early life stages through modified growth, survival, and/or fecundity.

During this analysis it became evident that the importance of the various functional relationships which interact to regulate populations of striped bass vary in importance according to geographic location. For example, in California, where cannibalism by older-year classes accounts for a large proportion of the juvenile mortality, a decreased survival of young of the year could be followed by a reduced juvenile mortality rate corresponding to the reduced number of cannibalistic individuals.

By comparison, cannibalism is uncommon on the Atlantic Coast, where it appears that fishing plays an important role in regulating the population size. For example, Fig. 10.6 shows that increases in striped bass commercial catches in the mid-Atlantic region are associated with declines in Hudson River catches. Furthermore, catches in the Hudson can be used to predict landings in the Atlantic five years later (R = 0.97** for 26 pairs of data). This relationship is not surprising, because the 16-in. size limit restricts catches to large individuals and thus would reflect fluctuations in abundance of mature fish returning to the river to spawn. Furthermore, inverse correlations were found to exist between the Hudson landings and both effort and catch by the Atlantic fishery in the previous year; thus it is concluded that fishing mortality is an important limiting factor in this region.

As a result of this study it is apparent that fishing plays a major role in regulating mid-Atlantic striped bass populations. Furthermore, the linear relationship that was found to exist between abundance of spawners and later recruitment to the fishery indicates that survival during that interval was not affected by the population density. Thus it is concluded that for some populations at least, mortality caused by entrainment of eggs and larvae of striped bass is very likely to result in a proportional reduction in recruitment to the fishery.

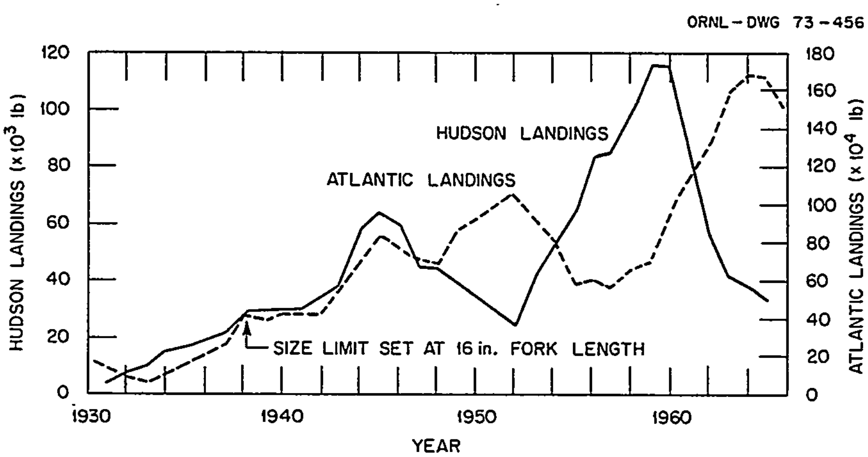

Fig. 10.6. Striped bass landings by commercial fisheries in the Hudson River and the mid-Atlantic region (data smoothed by threes).

11. Applied Aquatic Studies

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The consequences of radionuclides released to the environment either routinely or accidentally provide the basis for applied aquatic studies. The major objectives of these studies are (1) to determine the movement and concentration of radionuclides in aquatic ecosystems and (2) to determine the effects of radiation on aquatic organisms from the molecular to the population level. Of primary importance is the need for precise data on the environmental transport of radionuclides in order to calculate resultant doses to man. Also of importance is the need for information on the somatic and genetic effects of chronic low-level radiation on aquatic organisms. This information is needed to evaluate the impact of radionuclides released to aquatic ecosystems.

Chronically contaminated White Oak Lake (WOL) is a unique area to study the behavior and distribution of radionuclides in a natural ecosystem and to study natural populations of aquatic organisms which have been exposed to chronic irradiation for many generations. Data collected on radionuclide cycling in WOL yield concentration factors and food chain transfer coefficients which can be used in dose calculations. Such dose calculations can relate radiation effects to radionuclides in the environment. Laboratory experiments are conducted in conjunction with field studies and, in general, emphasize the influence of environmental factors on radionuclide cycling and radiation effects. Data from field and laboratory studies can be used to evolve models and provide basic data for predicting the environmental transport of radionuclides and the effect of irradiation on aquatic ecosystems.

RADIONUCLIDES IN THE SEDIMENTS OF WHITE OAK CREEK AND WHITE OAK LAKE

A study was made to provide an updated assessment of the concentrations of radionuclides in the bottom sediments of WOL and White Oak Creek for estimating the radiation dose received by organisms living in the bottom sediments. Shallow layers of sediments were collected along with core samples and analyzed for radionuclide concentrations. In the sampling program an attempt was made to include locations of sites previously sampled in 1965 and 1970.

Earlier studies of radionuclide concentrations in WOL indicated that the upper 6 in. of the sediments contained 80% of the ^{60}Co, more than 65% of the ^{137}Cs and ^{90}Sr activity, and about 55% of the ^{106}Ru.[4] The mean concentration, standard deviation, and percentage of the total site activity are summarized for each radionuclide in Table 11.1. Cesium-137 remains the most abundant radionuclide in the sediments and accounts for 62 to 86% of the total gamma emitters with the exception of two sampling sites. The majority of the activity is no longer associated with the upper 15

1. Dual capacity.
2. Biology Division.
3. Chemical Technology Division.

4. T. F. Lomenick and D. A. Gardiner, "The Occurrence and Retention of Radionuclides in the Sediments of White Oak Lake," *Health Phys.* 2, 567–77 (1965).

Table 11.1. Summary of radionuclide concentrations of bottom sediments from White Oak Lake

Site number	^{106}Ru pCi/g	S.D.	%	^{137}Cs pCi/g	S.D.	%	^{125}Sb pCi/g	S.D.	%	^{65}Zn pCi/g	S.D.	%	^{60}Co pCi/g	S.D.	%
1	94.5	14.0	5.4	1364.3	143.2	78.1	55.4	7.7	3.2	0			232.1	35.2	13.3
2	243.1	30.0	5.3	3575.1	303.8	77.9	145.6	26.4	3.2	43.6	10.6	1.0	579.3	29.0	12.7
3	396.4	38.9	7.0	3510.7	307.6	62.4	143.1	18.9	2.6	54.6	23.6	1.0	1524.4	171.6	27.1
4	546.6	24.8	7.9	4424.6	172.2	63.9	280.0	14.7	4.1	137.8	21.1	2.0	1533.7	88.6	22.2
5	270.9	30.9	5.6	3528.7	279.4	72.8	128.4	19.7	2.6	84.7	19.7	1.7	835.5	64.2	17.2
6	73.4	18.3	4.2	1420.7	308.5	80.2	18.9	6.6	1.1	0			265.5	110.3	14.6
7	75.7	28.8	4.3	1385.5	299.7	80.6	25.4	15.5	1.4	0			246.3	105.0	13.7
8	4.0	1.6	5.4	67.4	34.7	85.0	2.7	1.4	3.5	0.5	0.5	0.9	4.0	2.0	5.1
9	33.0	12.5	5.5	548.2	268.2	85.8	23.6	8.2	4.0	0.7	1.1	0.1	29.5	13.4	4.2
10	95.8	32.1	5.2	1543.0	330.9	85.4	58.9	12.5	3.3	3.3	3.0	0.2	107.4	19.1	6.0

cm of the sediments but is at a deeper location, somewhere between 16 and 34 cm. This is an expected result, since the yearly discharges of radionuclides to WOL have decreased since the first studies were made, and additional sedimentation has covered most of the original activity.

The ruthenium concentration has decreased considerably at almost every site. Radioactive decay is a major factor contributing to the decreased concentration. The upper shallow portion of the lake still contains the largest concentrations of ^{137}Cs, ^{90}Sr, and ^{65}Zn.

TRITIUM BEHAVIOR IN FISH FROM A CHRONICALLY CONTAMINATED LAKE

With the predicted increase in the world tritium burden, there is a need for information on the behavior of this radionuclide in local ecosystems in order to assess and predict both its potential environmental impact and dose commitment to human populations. Tritium behavior in fish from chronically contaminated WOL was studied under field and laboratory conditions to determine distribution and biological turnover.

Bluegills (*Lepomis macrochirus*) from an uncontaminated lake were placed in WOL and assayed for tritium over a 36-day period. Concentration ratios (tritium concentration in fish/tritium concentration in water) for whole-body and body-water tritium ranged from 0.6 to 0.9 and 0.8 to 1.0 respectively. Turnover of tissue-bound and body-water tritium was measured in goldfish (*Carassius auratus*) from WOL after placing them in uncontaminated water in the laboratory. Body-water tritium was eliminated at two exponential rates with biological half-lives of 0.2 and 0.9 hr. The initial fast component represented 96% of the initial level of body-water tritium. Tissue-bound tritium was eliminated at a single exponential rate with a biological half-life of 8.7 days (Fig. 11.1). Under long-term chronic exposure to tritium in food and water, fish do not appear to concentrate tritium in either their body water or tissue-bound component.

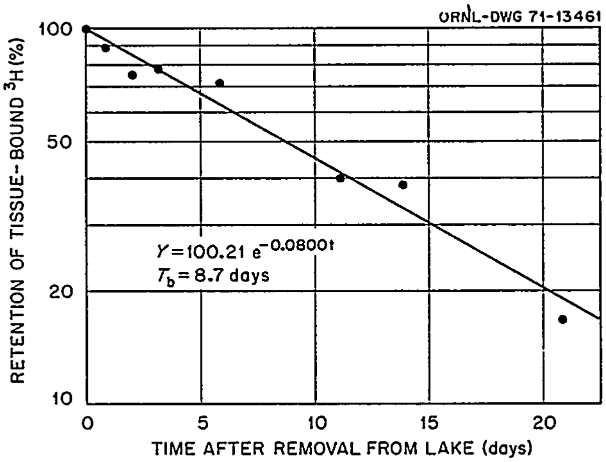

Fig. 11.1. Retention of tissue-bound tritium in goldfish from White Oak Lake.

LONG-TERM CYTOGENETIC STUDIES ON *CHIRONOMUS TENTANS*

The natural populations of organisms inhabiting WOL are exposed to chronic irradiation significantly higher than background. Very few studies have been conducted on such populations. From 1960 to 1963, cytogenetic studies were conducted on the natural populations of *Chironomus tentans* inhabiting the radioactive bottom sediments of WOL and White Oak Creek. These studies showed that an increased number of chromosome aberrations were being produced in the irradiated population. However, these aberrations did not persist or become established in the population but were eliminated by selection or by genetic drift. Also, chromosomal polymorphism was the same in the irradiated and control populations.

Ten years (approximately 50 generations) later, the *Chironomus* larvae from WOL were again analyzed for chromosome aberrations. In 1960, the dose rate received by the *Chironomus* larvae living in the radioactive bottom sediments was calculated to be 230 rads/year. The dose rate had decreased to 11 rads/year in 1970 as a result of decreased discharges of radioactive effluents to WOL. In the current analysis which is to extend through 1973, salivary chromosomes of 684 larvae have been analyzed for chromosome aberrations. Comparison with the results of 692 larvae analyzed from 1960 to 1963 showed a decrease in the frequency of radiation-induced aberrations and no changes in chromosomal polymorphism. The data strongly suggest that the natural population of *Chironomus*, which has been exposed to chronic irradiation for many generations, was surviving with no detectable changes in the natural chromosomal polymorphism. In addition, no radiation-induced aberrations have become established in the population, and the frequency of radiation-induced aberrations has decreased as the dose rate decreased.

EFFECTS OF RADIATION AND TEMPERATURE ON THE CHANNEL CATFISH, *ICTALURUS PUNCTATUS*

To evaluate the effects of radiation on an aquatic ecosystem, the radiation sensitivity of the various organisms must be known. Although radiation studies have been conducted on many species of fish, no information is available on the widely distributed catfish family. This experiment tested the effects of ^{60}Co gamma radiation and temperature on the channel catfish, *Ictalurus punctatus.* Groups of ten catfish which were acclimated to either 15, 25, or 30°C water were given radiation doses ranging from 500 to 2500 rads. The $LD_{50\text{-}30}$ dose for fish maintained in 25°C water was approximately 1100 rads. This is a relatively low dose when compared with the $LD_{50\text{-}30}$ of other fish. Temperature greatly increased or decreased the length of time the catfish lived after irradiation. For example, at 30°C a dose of 1500 rads was lethal to all catfish in 8 days, whereas for the same dose some fish survived for 32 days when they were maintained at 25°C and for 98 days when they were maintained at 15°C. Besides providing additional information on the radiation sensitivity of another family of aquatic organisms, this study demonstrates the importance of temperature when expressing the LD_{50} of poikilotherms.

RADIATION EFFECTS ON AQUATIC COMMUNITIES

During a preliminary investigation of juvenile fish from WOL in 1969, a relatively high incidence of abnormalities was observed in several species, particularly in goldfish. A previous study of WOL *Gambusia* populations indicated that abnormalities were higher than in other natural populations of the same species, but the frequency of occurrence was still relatively small: 0.4% of embryos examined. The results reported here constitute a highly preliminary phase of an investigation whose objective is to determine the causation for the abnormalities in WOL fish – in particular, whether the abnormalities may be linked with chronic low-level exposure to ionizing radiation.

In a variety of field and laboratory studies, a high incidence of abnormalities has been correlated with unfavorable environmental conditions during ontogeny (temperature, oxygen, water chemistry, etc.), hormonal imbalance, genetic factors, and parasitic infiltration. Since WOL is the "holding pond for Laboratory wastes," factors other than ionizing radiation, such as sanitary and chemical wastes, are thus not easily eliminated as a potential cause of abnormalities. Several toxic chemical entities, particularly chromium (as chromate and its reduction products) and phenols, are discharged in large quantities to WOL via White Oak Creek. The yearly average concentration of chromium (as chromate) has been as high as 0.26 ppm at the White Oak dam in recent years.

Goldfish tissues and gastrointestinal contents and potential food organisms (algae and invertebrates) from WOL were radioassayed during 1971. Highest concentrations of all radionuclides were found in the goldfish gastrointestinal contents, which were morphologically and radiologically similar to WOL bottom sediments. Concentrations in food and goldfish tissues were approximately one and two orders of magnitude lower, respectively, than those found in the gastrointestinal contents. Values in gastrointestinal contents were approximately one-half the reported mean surface concentrations in WOL sediments. Calculation of the expected absorbed dose rate to gonadal tissue of adult goldfish indicated that the major contribution (240 millirads/day) was made by ^{60}Co and ^{137}Cs gamma photons originating in WOL sediments. Other nontrivial contributions were made by beta-gamma emissions from gastrointestinal contents (19 millirads/day) and sur-

Table 11.2. Effect of different concentrations of chromium (Cr^{3+}) on carp embryos

Concentration (ppm)	Total hatched[a]	Number abnormal	Total dead	Percent normal offspring	Percent hatched at 45 hr
Controls	279	2	6	97.2	89.2
1	407	13	3	96.2	69.8[b]
3	439	16[c]	3	95.7	56.7[b]
10	626	37[b]	2[c]	94.1[c]	27.5[b]
30, 100	100% mortality – no embryos survived beyond early cleavage.				

[a]Total of four replicates.
[b]$P > 0.99$ when compared with controls.
[c]$P > 0.95$ when compared with controls.

rounding body tissues (<1 millirad/day). The total, an estimated gonadal dose of 0.26 rad/day, was below the 1 rad/day chronic irradiation threshold believed necessary to produce detectable effects in aquatic organisms.

Fertilized carp eggs (prepared according to previously described techniques) were incubated in varying concentrations of chromium (as $CrCl_3$) at 26°C. The results, shown in Table 11.2, indicate a lethal threshold between chromium concentrations of 10 and 30 ppm. At lower concentrations, mortality is apparently decreased with increasing concentration, a possible result of microbial inhibition by trivalent chromium. Abnormality frequencies apparently increase with increasing chromium concentration. The net result is that the number of normal offspring at hatching per 100 fertilized eggs (percent normal offspring) steadily decreases with increasing chromium concentration but not as significantly as it might if mortality was unaffected. Perhaps the most striking effect of chromium treatment (1 to 10 ppm) is the marked increase in developmental time required to reach the hatching stage (shown as the percent hatch at 45 hr after fertilization).

Radionuclide discharges into WOL have declined drastically since the early 1960s; as a consequence, radiation dose rates have steadily declined in the intervening period. Since the late 1960s, however, uses of toxic cooling tower chemicals (chromate, phenols, etc.) have increased sharply, particularly since 1968. Expected average concentrations of total chromium at White Oak Dam have been 0.5 to 1.0 ppm in three of the last four years. Concentrations in the upper shallow end of WOL (location of White Oak Creek mouth and major fish spawning areas) are expected to exceed this value considerably. Preliminary results on carp eggs indicate that chromium concentrations of this magnitude may be capable of producing significant increases in abnormalities when embryos alone are exposed. Continuous exposure throughout ontogeny may significantly increase the severity of any effect. Thus, if juvenile fish surveys in WOL (to be conducted in 1973) indicate that a high frequency of abnormalities still persists despite declining radiation dose rates, future studies should concentrate on chemical factors and possible synergistic combinations of chemicals, environmental variables, and ionizing radiation, rather than on ionizing radiation alone.

THE NICHE-VARIATION HYPOTHESIS: AN EXPERIMENTAL STUDY WITH *DROSOPHILA* POPULATIONS

The Van Valen niche-variation hypothesis, which postulates a positive relationship between niche width and morphologic (or genetic) variability, is difficult to test using natural populations. In addition, the lack of universal agreement on niche quantification methodology has made interpretation of collected data difficult. There seem to be major problems in testing the Van Valen hypothesis due to sample bias and in the need to eliminate the effects of immigration and directional selection. Most studies (usually on birds) seeking to determine the relationship between variability and niche width have operationally defined wide niches for certain species and narrow niches for other species. The difference in morphological variability of characters between the two groups is then used to test the hypothesis. Data presented by Blaylock and Shugart[5] were used to perform the converse test on the

5. B. G. Blaylock and H. H. Shugart, Jr., "The Effect of Radiation Induced Mutations on the Fitness of *Drosophila* Populations," *Genetics* (in press) (1972).

model, namely, testing for differences in niche width under conditions of different degrees of (genetic) variability.

The present study[6] validates the Van Valen niche-variation model under certain rather constrained conditions. With highly inbred strains of *Drosophila simulans,* increased variability (induced by the use of low-level radiation to increase the mutation rate) increased the niche width of the population. Although the niche-variation model implies relation, not causality, between niche width and variability, these experiments indicate that higher variability confers a wider niche. Evidence cited by Van Valen indicates that there is reason to expect a greater niche width to increase variability. This being the case, niche width and variability would be mutually causal, and the relationship between the two would have positive feedback attributes.

CHLORINATION EFFECTS ON SEWAGE EFFLUENTS AND NATURAL WATERS

Sterilization by contact with gaseous chlorine is a routine processing step used for sanitary sewage plant effluent treatment and for treatment of process and potable water. But all of these water sources contain dissolved organic contaminants. Little definitive information is available concerning the potential hazards resulting from the chlorination process; therefore, a study is under way to determine if stable chlorinated organic compounds are produced during the chlorination step and whether or not they exhibit high toxicity. The principal investigative tool for this analysis is high-resolution liquid chromatography, which has proven extremely successful in analysis of complex body fluids.[7-10] Such systems are now being used to study, on a molecular basis, organic contaminants in water.[11] This type of analytical system should ultimately provide useful quantitative information concerning many refractory organic compounds in waters.

Preliminary studies have been made on the chlorination of sanitary sewage effluents. In some tests the chlorination was performed in the field at sewage plants, while in others, laboratory tests were made. These results showed that there were indeed effects of chlorination on the molecular contaminants in the effluents of both the primary and secondary stages of sewage treatment. Comparison of the chromatographic results of the chlorinated effluents with those of the unchlorinated effluents showed that some chromatographic peaks disappeared, while others were generated. This indicated that the molecular species were changed by the chlorination process. It is important to determine whether these effects of chlorination are a consequence of oxidation or result from chlorine addition and/or substitution. The most direct and sensitive technique for determining this is to chlorinate effluents using a radioactive tracer.

It has recently been shown by radioactive tracer experiments that additional chlorinated organic residues were created during chlorination of primary sewage effluent under conditions similar to those occurring in sewage treatment plants. Several different chromatographic experiments were performed which clearly demonstrated that (1) new chlorine-containing compounds are found in sewage plant effluents after chlorination, (2) these chlorinated residues are not artifacts of the sample preparation procedure, (3) the chlorinated residues result from chlorination and not from chloride ion interaction and are therefore fairly stable in aqueous media, and (4) the chlorinated residues are not inorganic but organic in nature.

For example, in one experiment, 2 liters of unchlorinated primary effluent from the Oak Ridge West Sewage Plant was chlorinated with 18.7 mg of chlorine gas containing approximately 0.12 mCi of ^{36}Cl. This mixture was then concentrated to a volume of 3.5 ml in a rotary evaporator. When 280 μl of concentrate was separated by high-resolution anion exchange chromatography, 37 radioactive chromatographic peaks containing ^{36}Cl were found (Fig. 11.2). Many of these peaks also had a substantial amount of ultraviolet absorbance which could be attributed to their organic moiety.

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6. H. H. Shugart, Jr., and B. G. Blaylock, "The Niche-Variation Hypothesis: An Experimental Study with *Drosophila* Populations," *Amer. Natur.* (in press).

7. C. D. Scott, J. E. Attrill, and N. G. Anderson, "Automatic, High Resolution Analysis of Urine for Its Ultraviolet-Absorbing Constituents," *Proc. Soc. Exp. Biol. Med.* 125, 181 (1967).

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10. R. L. Jolley and M. L. Freeman, "Automated Carbohydrate Analysis of Physiologic Fluids," *Clin. Chem.* 14, 210 (1968).

11. S. Katz, W. W. Pitt, Jr., C. D. Scott, and A. A. Rosen, "The Determination of Stable Organic Compounds in Waste Effluents at Microgram per Liter Levels by Automatic High-Resolution Ion Exchange Chromatography," *Water Res.* 6, 1029 (1972).

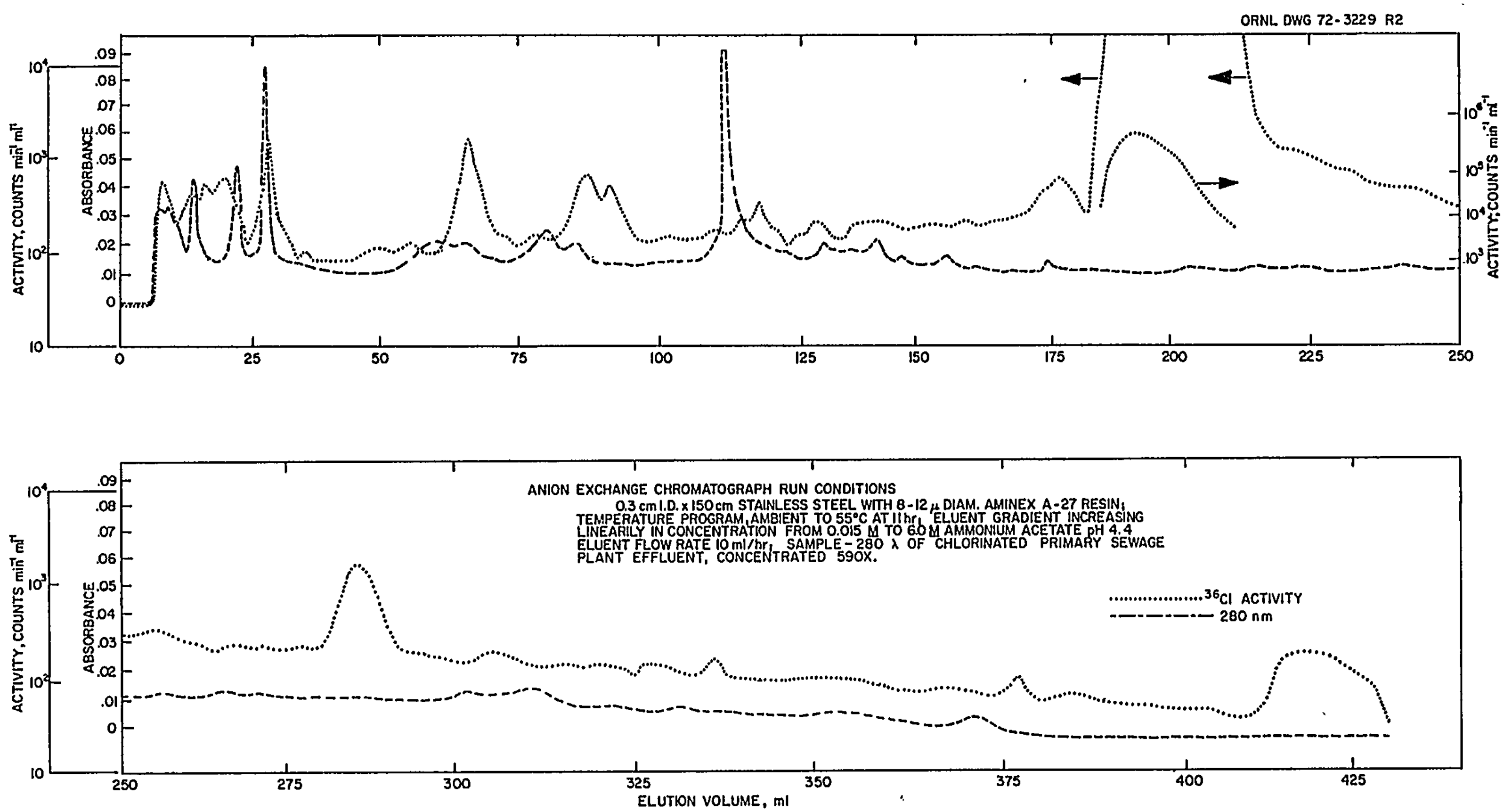

Fig. 11.2. Ultraviolet-absorbing and chlorinated constituents in Oak Ridge West Sewage Plant primary effluent.

Because the levels of organic compounds in natural waters may be significantly less than in sewage effluents, it will be necessary to concentrate these samples to a much greater extent. Work in this area is being directed toward studying sorption processes and low-temperature distillation followed by lyophilization as means of sample concentration. At the present time, the latter is the method of choice, since earlier studies with sewage effluents indicated greater than 85% recovery of the organic carbon in the concentrate. Unfortunately, however, in preliminary studies, concentration of water from Watts Bar Reservoir using low-temperature distillation resulted in less than 30% retention of the organic carbon content in the concentrate. This problem will be studied in more detail.

12. Ecological Sciences Information Center

C. J. Oen

B. N. Collier C. T. Sanders
H. A. Pfuderer B. B. McMullin
P. J. Gillespie F. A. Martin

The Ecological Sciences Information Center (ESIC) provides information services to investigators of the Environmental Sciences Division, the Oak Ridge National Laboratory, other AEC installations, and others. This includes a program directed toward developing a comprehensive base of information to include both literature references and numerical data relevant to the movement, cycling, and concentration of elements, isotopes, natural materials, and environmental pollutants in different ecosystems. The effects of radiation on species and populations, the cycling of radionuclides, and the effects of thermal enrichment are of particular interest.

A computerized system of information storage and retrieval is used to cover the vast, diffuse literature quickly and specifically. This capability enables investigators to keep abreast of current developments in their field, to review the allied areas quickly, and to provide the background information required in multidisciplinary or systems-analysis approaches to complex ecological problems. The following paragraphs describe some of the projects in which ESIC is involved.

The thermal effects project represents a cooperative venture between the information group and the thermal effects research group. Approximately 400 references from the 1971 literature have been input to the computer files and were published as a bibliography. Scanning, selection, and input of 1972 literature are in progress. These references are of special interest to the AEC impact statement work groups.

Early in 1972 the Environmental Plutonium Data Base was organized in support of the Nevada Applied Ecology Group of the USAEC Nevada Operations Office at Las Vegas, Nevada. The subjects of central concern are the movement and interactions of plutonium within various ecosystems. Related material, such as biological effects of plutonium, methods of plutonium analysis in soils, and dispersion of fallout from nuclear explosions, is also included. A data base of over 1500 items is available for search. Services from this data base are being requested. Suggestions from users are solicited and evaluated.

C. W. Francis is working with the information center to prepare for input over 1200 references he has selected as relevant to the subject of radionuclides in the plant-soil relation. Members of our staff have assisted him with library work and with document preparation.

An ESIC staff member chose background material for a 25-year overview of ecosystem analysis.[1] All selected articles were abstracted, and indexes were developed to provide consistency throughout.

Although ESIC is now primarily building its files, services are provided and publications are sent to a variety of users. Table 12.1 briefly describes search requests by user affiliation and subject area.

1. D. E. Reichle and S. I. Auerbach, "Analysis of Ecosystems," pp. 260–81 in *Future Directions in the Life Sciences*, ed. by J. Behnke, AIBS, Washington, 1972.

Table 12.1. Search requests from September 30, 1971, to September 30, 1972

User affiliation	Number of requests				
	Radiobiology	Aquatic biology	Other environmental sciences	Other	Total
Environmental Sciences Division	12	6	9	14	41
Oak Ridge National Laboratory	7	7	7	9	30
Other AEC groups	7	2	6	13	28
Other government agencies	2	1	1	2	6
Environmental Plutonium Data Base	1	1			2
Other	1	2	2	3	8
Foreign	1			2	3
Education	3	4	2	2	11
Total	34	23	27	45	129

13. Education

J. P. Witherspoon

SCOPE

The objective of educational activity is to disseminate the use of advanced methods and techniques available at Oak Ridge National Laboratory for studying and controlling problems associated with energy, radioactivity, and all other forms of environmental pollutants and chemical cycles. To improve the "quality of man's environment" in the face of environmental degradation from increasing populations requires innovative education and training activities in basic and applied environmental sciences as well as in radiation protection.

Training activities are planned for participation ranging from outstanding college undergraduates to senior postdoctoral-level personnel. Undergraduate research project experiences have provided a powerful stimulus and an orientation toward quantitative environmental research with more teamwork than usual in the participant's formative years. Laboratory graduate participants have an opportunity to become familiar with modern experimental techniques and data analysis, which frequently give them a new outlook on the social relevance of the problems encountered by man's cultural alteration of diverse environments.

EDUCATIONAL ACTIVITIES

This year, 20 undergraduate students participated in Division research activities for periods ranging from 10 to 16 weeks. All of these students completed research projects under the direction of senior staff members. Undergraduate problems and the number of students in each were as follows:

NSF Undergraduate Research Participants	10
ORAU Undergraduate Research Participants	3
Cooperative Curriculum Program	4
ORAU–Great Lakes Colleges Association	3

The research accomplishments of these outstanding college undergraduates are listed under appropriate program areas throughout this report.

Eleven graduate students (nine doctoral and two master's degree candidates) did full-time thesis research in the Division this year. Three of these students (two Ph.D. and one M.S.) completed their theses, and an additional three completed their research work. Staff members not only were involved in an advisory and training capacity but also served on graduate committees at the students' academic institutions.

At the postdoctoral level, 11 faculty members and 3 Presidential Interns affiliated with the Division. Six of the visiting faculty assisted senior staff members in the preparation of environmental impact statements; the remainder were involved in research activities.

In addition to an increased level of in-house student and faculty participation this year, five Division staff members held faculty appointments and taught courses at the University of Tennessee. Many others served as resource people for governmental, educational, and private institutions seeking information on environmental matters. A listing of these activities is given under the "Professional Activities" section of this report.

A new development this year was the creation at ORNL of a school to train staff in the area of environmental assessment of technological events. Some of the Division staff will participate in both course curriculum and on-the-job training phases of this school.

The various Division interactions are summarized in Table 13.1.

Table 13.1 Overview of institutional and university collaboration in research during the previous 12-month period

Institution	Relationship to program
Tennessee Valley Authority, Division of Forestry, Fisheries, and Wildlife	Local environment impact and land-use studies
Tennessee State Game and Fish Commission	Censusing of local wildlife populations
Duke University Rensselaer Polytechnic Institute University of Georgia University of Wisconsin	Collaborating IBP research sites
University of Wyoming Kenyon College University of Minnesota	Oak Ridge Associated Universities faculty participation
Saint Andrews Presbyterian College	Chronic radiation effects on animal populations
Lawrence Radiation Laboratory	Tritium movement in the environment
U.S. Forest Service, Coweeta Hydrologic Laboratory	Hydrologic data processing-IBP collaboration
Pacific Northwest Laboratory, Battelle Memorial Institute	Comparative radiation sensitivity of vertebrates
University of Tennessee University of Michigan University of Kentucky Purdue University Wabash College Brock University Northwestern University	Graduate student training and research subcontracts
USAEC, Division of Biomedical and Environmental Research National Science Foundation, Ecosystem Analysis and RANN Programs National Academy of Sciences–National Academy of Engineers Department of Defense, Office of Civil Defense, U.S. Air Force, Corps of Engineers	Advisory panels, technical staff assistance, program development

14. Forest Management

D. M. Bradburn E. H. Rosenbalm

The forest management program on the AEC Oak Ridge Reservation is now in its eighth year of operation. The forest is managed on a multiple-use, sustained-yield basis with two primary objectives – an ecological park for research studies and high-quality timber products. Due to the excellent study facilities provided by the forest, research by the Environmental Sciences Division takes priority over timber production.

In conjunction with the ecological park concept and intense forest management, a renewed regeneration program was begun in FY 1972 to regenerate areas that are understocked or nonproductive for timber products. The site preparation techniques used were controlled burning, clearing, raking into windrows and burning, and disking, with these techniques varying depending on primary site conditions. Machine planting follows, using either loblolly pine (*Pinus taeda*) or yellow poplar (*Liriodendron tulipifera*), whichever is most suited for that particular site. For FY 1972 there were 23 acres planted, of which 22 acres were planted with 21,500 loblolly pine and approximately 1 acre with 800 yellow poplar seedlings.

The site preparation program for FY 1973 was begun in June 1972, with approximately 230 acres scheduled for site preparation and planting. This required having a full-time equipment operator assigned to the forest management department to do the clearing work and also controlled burning and tree planting.

New aerial photographs were made of the AEC Oak Ridge Reservation in FY 1972 at a cost of $2500. The photos will be used to type map the entire Reservation by compartments and to facilitate all forest management activities as well as research studies.

Timber stand improvement for FY 1972 included basal injection with 2,4-D and 2,4,5-T into unwanted hardwood species in pine stands. Approximately 45 acres were treated in this manner over the past year. Another treatment included in this program is controlled burning. No controlled burning in pine stands was done in FY 1972, since approval was not granted by AEC until the winter burning season was past. This program also includes site preparation burning, some of which was done at the beginning of FY 1973.

FY 1972 was a busy year for timber product removals from the AEC Oak Ridge Reservation. The ten-year timber sale contract with Longleaf Industries, Inc., was in its third year of timber harvesting. Longleaf cut four timber sales on the Reservation, totaling 1,464,166 bd ft of standing timber, with gross revenue from these sales amounting to $30,304.17. Total pulpwood sales on bid to Anderson County Pulpwood amounted to 2179 cords grossing $9,266.11, bringing total gross revenue to $39,570.28.

Southern pine beetle activity for 1972 was limited to small scattered spots of less than one acre. With only one exception, these infected spots were too small to warrant treatment. One area of approximately 1 acre of loblolly pine in compartment 23 was cut for pulpwood due to a moderate infestation of both the Southern pine beetle (*Dendroctonus frontalis*) and the black turpentine beetle (*Dendroctonus terebrans*). With the use of controlled fire in pine plantations to remove thinning slash where these insect pests overwinter, the Southern pine beetle problem should diminish on the AEC Reservation during the next management cycle.

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"Modeling Successional Phenomena: Considerations in Time and Space," Biology Department, State University of New York at Albany, January 22, 1972, Albany, New York.

"Dynamic Ordination and State Space Analysis," Botany and Zoology Departments, University of Wisconsin, March 2, 1972, Madison, Wisconsin.

"Niche Quantification and the Concept of Niche Pattern," Zoology Department, University of Arkansas, March 23, 1972, Fayetteville, Arkansas.

"A Succession Model for Large Regions: Rationale and Initial Simulation Results," Botany and Zoology Departments, University of Arkansas, March 24, 1972, Fayetteville, Arkansas.

"A Scientist Views Highway Location," SAVE conference on transportation, July 20, 1972, Atlanta, Georgia.

Systems Ecology (Botany 5510, 5520), University of Tennessee (two-quarter graduate course), Winter and Spring 1972, Knoxville, Tennessee.

R. I. Van Hook, Jr.

"Radioecology Applied to Insects and Related Arthropods," Science Division, Northeast Missouri State College, 1972, Kirksville, Missouri.

J. P. Witherspoon

"Ecological Research and the Environmental Crisis," Brevard College, Science Day, October 27, 1971, Brevard, North Carolina.

"Ecological Research at ORNL," Atlanta High School Science Students, January 21, 1972, ORNL.

"Radioecology," Tennessee Junior Science and Humanities Symposium, March 3, 1972, ORNL.

"Radiation Ecology," Science Classes of Bishop Moore High School (AIBS Traveling Lecture Program), March 9–10, 1972, Warminster, Pennsylvania.

"Environmental Research at ORNL," Ecology Students and Faculty of Vassar College, March 20, 1972, ORNL.

"Ecology and the Environmental Crisis," Illinois Academy of Science, April 28, 1972, Macomb, Illinois.

"Environmental Impact of Nuclear Power Plants," Seminar, Physics Department, Auburn University, May 5, 1972, Auburn, Alabama.

"Ecology at ORNL," Ecology Students and Faculty, Eastern Illinois University, May 12, 1972, ORNL.

"The Energy Crisis," Oak Ridge High School, May 15, 1972, Oak Ridge, Tennessee.

"Radioactivity and Ecosystems," Applied Ecology for College Chemistry Teachers, ORAU, June 29, 1972, Oak Ridge, Tennessee.

"Ecological Effects of Ionizing Radiation," University of Tennessee School of Medicine Resident Radiologists, July 14, 1972, Memphis, Tennessee.

"Use of Radioisotopes in Terrestrial Ecology," Aquatic Center, Tennessee Technological University, July 20, 1972, Tech Aqua Center, Tennessee.

"Undergraduate Educational Opportunities at ORNL," Southern Colleges and Universities Union, Vanderbilt University, June 15, 1972, Nashville, Tennessee.

THESES

C. J. Richardson

The Use of Stomatal-Resistance, Photopigments, Nitrogen, Water Potential, and Radiation to Estimate Net Photosynthesis in Liriodendron tulipifera *L. – A Physiological Index,* Ph.D. thesis, University of Tennessee, 1972.

P. Sollins

Organic Matter Budget and Model for A Southern Appalachian Liriodendron *Forest,* Ph.D. thesis, University of Tennessee, 1972.

PROFESSIONAL ACTIVITIES

S. I. Auerbach

Director, Eastern Deciduous Forest Biome, Analysis of Ecosystems, International Biological Program.

Member, Executive Committee, U.S. National Committee for the IBP.

President, Ecological Society of America, 1971–1972.

Member, U.S. National Committee of the International Union of Biological Sciences.

Member, Special Committee on Biological Water Quality of the Ohio River Valley Water Sanitation Commission.

Member, Editorial Board of *International Journal of Environmental Sciences.*

Member, Editorial Board of *Radiation Botany.*

Member, Advisory Board, *Advances in Radiation Biology.*

Member, Board of Trustees, The Institute of Ecology.

Member, Board of Ecological Advisors of the Bureau of Reclamation.

Participant in AEC educational film entitled "No Turning Back."

President, The Scientific Research Society of America, Oak Ridge Branch.

B. G. Blaylock

Lecturer in Zoology and Member of graduate faculty, University of Tennessee, Knoxville, Tennessee.

C. C. Coutant

National Academy of Sciences – National Academy of Engineering, Water Quality Criteria Revision Project, Member, Panel on Freshwater Aquatic Life and Wildlife.

National Academy of Engineering, Energy Panel of the Committee for the Study of Research Applied to National Needs.

Research Committee, Water Pollution Control Federation.

R. C. Dahlman

Panel Chairman, Agro-Ecological Assessments, Workshop on Food, Crop, and Livestock Survival in the Event of Nuclear War, AEC-OCD-USDA, Oct. 16–19, 1972, Front Royal, Virginia.

B. E. Dinger

Coordinator, U.S.–IBP Interbiome Primary Production Workshop, Oak Ridge, Tennessee, April 13–14, 1972.

Participated in Spring Camporee, Smoky Mountain Council of Boy Scouts, Norris, Tennessee, May 6, 1972.

"Ecological Research at ORNL," field tour and discussion of photosynthesis studies and micrometeorology at ORNL-EDFB intensive study site to:

1. Forest Management Class, University of Tennessee, July 19, 1972 (with G. S. Henderson).
2. Recreation and Wildlife Management Class, University of Tennessee, August 7, 1972 (with N. T. Edwards).
3. U.S.-IBP International Woodlands Workshop Group, August 25, 1972 (with G. S. Henderson).

Served on ORNL Staff Review Board for USAEC Draft Environmental Statement on Shoreham Nuclear Power Station, April 25 and 26, 1972.

N. T. Edwards

Participant, International IBP Woodlands Workshop, ORNL, Oak Ridge, Tennessee, August 14–26, 1972.

"Research at ORNL-IBP Study Sites," field tour and discussion to: Recreation and Wildlife Class, University of Tennessee, July 19 and August 7, 1972 (with Blaine Dinger).

J. W. Elwood

Demonstration of measurement of water quality at Fall Conservation Camporee, Boy Scouts of America, Camp Pellissippi, Lafollette, Tennessee, May 6, 1972.

Member of task group assigned to prepare AEC Environmental Impact Statements for Palisades, Surry, North Anna, and Mendocino Power Plants.

R. A. Goldstein

Participant, International Tundra Biome Systems Workshop, March 1972, San Diego, California.

Participant, Crop Ecosystems Simulation Group Workshop, March 1972, Clemson University, Clemson, South Carolina.

Participant, Hydrological modeling workshop, April 1972, University of Wisconsin, Madison, Wisconsin.

Guest, National Research Council of Canada, Ottawa, Canada, May 1972, discussed modeling of mercury dynamics in aquatic ecosystems.

Member, Basic Physical Sciences Assessment Council, Oak Ridge National Laboratory.

W. F. Harris

Member, AIBS Visiting Radiation Biologists Program.

Process Coordinator, Terrestrial Primary Production, EDFB, U.S./IBP.

Member, Interbiome Primary Productivity Committee, U.S./IBP.

Field tour of ORNL Ecological Programs (1) Advanced Ecology class, Wabash College, April 7, 1972; (2) American Association of Community and Junior Colleges, July 21, 1972.

Participant in Boy Scouts' Nature Study Camporee, May 6, 1972, Lafollette, Tennessee.

G. S. Henderson

Process Coordinator, Terrestrial Mineral Cycling, Eastern Deciduous Forest Biome, U.S.-IBP.

Member, Interbiome Mineral Cycling Committee, U.S.-IBP.

Advisor to Pre-Coop Students

Participant, IBP Analytical Chemistry Workshop, Madison, Wisconsin, March 15–16, 1972.

Conducted field tours and discussions for the following groups:

1. TVA, October 18, 1971;
2. Professional Engineer Society, October 14, 1971;
3. Coniferous Biome IBP Representatives, October 19, 1971;
4. U.S. National Committee for IBP, November 5, 1971;

5. University of Tennessee Forestry Class, July 19, 1972,
6. International Woodlands Workshop, August 25, 1972.

J. W. Huckabee

Consultant at National Research Council of Canada, Ottawa, Ontario, May 1–4, 1972, with R. A. Goldstein, Modeling of Mercury Behavior in the Ottawa River.

S. V. Kaye

Served as Chairman of Project SOAR (Save Our American Resources), Pellissippi District, Great Smoky Mountain Council, Boy Scouts of America.

Organized Ecology Program for Spring Camporee, Boy Scouts of America, Camp Sequoyah, Lafollette, Tennessee. Staff members presenting lectures included: J. W. Elwood, B. E. Dinger, W. F. Harris, W. C. Johnson, D. E. Reichle, and R. I. Van Hook.

Task group member of Committee 4 on Application of Recommendations, International Commission on Radiological Protection.

D. J. Nelson

Consultant, Advisory Committee on Reactor Safeguards.

Member-at-large, Board of Directors, American Society of Limnology and Oceanography.

Member, U.S. National Committee for the International Union for Quaternary Research, National Academy of Sciences, National Research Council.

Consultant, Mobile District, U.S. Army Corps of Engineers.

Lecturer in Zoology and Member of graduate faculty, University of Tennessee, Knoxville, Tennessee.

Participant, Workshop on Stream Ecology, Coniferous Forest Biome, U.S.-IBP, Corvallis, Oregon.

J. S. Olson

Professor of Biology (part time), Department of Botany and graduate program in Ecology, University of Tennessee. (Major Professor for Phillip Sollins).

Series Editor, *Ecological Studies, Analysis and Synthesis,* Springer-Verlag, Berlin-Heidelberg-New York.

Consulting Editor, *Encyclopedia of Science and Technology* (and *Yearbook*), McGraw-Hill, New York.

Study Committee for organizing The Institute of Ecology (TIE), Ecological Society of America.

Adviser for Earth Day 1972, Oak Ridge High School, and Students for Earth's Future.

Program Section Chairman, The Carbon Cycle (Symposium), Brookhaven National Laboratory, May 1972.

Chairman, Committee on Environmental Terminology (preparing draft environmental thesaurus for U.N. Stockholm Conference (June 1972) on the Human Environment as an NSF contribution; reviewed at a Forum on Environmental Information, hosted by Environmental Protection Administration (September 1972).

International Biological Program, Productivity of Terrestrial Ecosystems (IBP/PT) International Section (Fifth General Assembly of IBP, Seattle, Washington, August–September 1972).

Interbiomodeling coordination representative at Fort Collins, Colorado (January 1972).

International Coordinator, Eastern Deciduous Forest Biome, U.S.–International Biological Program.

Chairman, National Academy of Sciences Committee for En route Visits related to the International Biological Program.

Member, National Academy of Sciences Committee for the Fifth General Assembly of the International Biological Program.

Principal Investigator, for NSF Office of International Programs grant on "Analysis of World Ecosystems" for three workshops (in Oak Ridge, Tennessee, and Fort Collins, Colorado, in August 1972, and at Nevada Test Site, Arizona, New Mexico and Utah in September 1972).

Participant in Oak Ridge, Tennessee, Workshop on World Woodlands of the IBP/PT international section, hosted by ORNL.

Member, National Academy of Sciences Committee on Radiobiology.

Oak Ridge Associated Universities/ORNL Traveling Lecturer 1971–72.

Environmental Impact Evaluation (Hatch, Farley, Limerick, and Arkansas Nuclear Stations).

R. V. O'Neill

Member, U.S. International Biological Program Interbiome Modeling Committee

Modeling Program Coordinator, U.S. International Biological Program, Eastern Deciduous Forest Biome.

Member, Coordinating Committee, International Biological Program Woodlands Synthesis Meeting, Oak Ridge, August 12–26, 1972.

U.S. Representative, International Synthesis Workshop on Arthropod Decomposition, Louvain, Belgium, July 18–20, 1972.

Session Chairman, Gordon Research Conference on Water Quality Modeling, August 28–September 1, 1972.

D. E. Reichle

Lecturer, University of Tennessee graduate program in Ecology.

Cochairman, International Woodlands Coordinating Committee, International Biological Program.

Editorial Board, *Ecological Monographs.*

Member, Coordinating Committee, University of Tennessee Institute of Radiation Biology.

Member, Panel on General Ecology and Ecosystem Analysis, National Science Foundation.

Member, Executive Committee, Eastern Deciduous Forest Biome, Analysis of Ecosystem Program, U.S.-IBP.

Member, Scope Commission for a *Program For Analysis of World Ecosystems* (PAWE).

Member, Planning Committee for the *Productivity Symposium,* V IBP General Assembly.

Member, Committee on Land Use Planning, Tennessee Citizens for Wilderness Planning.

Member, Steering Committee, ORNL Ph.D. Recruitment Program.

Member, ORNL Graduate Selection Panel.

P. S. Rohwer

Treasurer, East Tennessee Chapter of the Health Physics Society.

Scientific Advisor, Health Physics and the Law, "A Moot Trial of an Alleged Radiation Injury," presented at the 17th Annual Meeting of the Health Physics Society, Las Vegas, Nevada, June 15, 1972.

Member, Program Review Team, DBM/AEC Program Review of the Environmental Program at Lawrence Livermore Laboratory, March 6–9, 1972.

R. I. Van Hook, Jr.

Chairman, Symposium on The Impact of Heavy Metals on Ecosystems, AIBS, University of Minnesota, Minneapolis, Minnesota.

Lecturer in the American Institute of Biological Sciences Radiation Biology Program.

Toxic Materials in the Environment, a proposal submitted to the National Science Foundation (editor).

J. P. Witherspoon

Lecturer in Radiation Ecology, Department of Botany, University of Tennessee, Knoxville, Tennessee.

Lecturer in American Institute of Biological Sciences Visiting Radiation Biologists Program.

Lecturer in the ORAU Traveling Lecture Program.

Graduate Thesis Committee, T. L. Cox (Ph.D.) and Carol Matti (M.S.) University of Tennessee, Knoxville, Tennessee.

ORNL Representative in meetings with the American Association of Junior and Community Colleges.

Environmental Sciences Division Publications

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Environmental Sciences Division
Building 2001
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, Tennessee 37830

Publications marked by an asterisk are out of print – none are available.

1. ROHDE, C. J., JR. 1956. A modification of the plaster-charcoal technique for the rearing of mites and other small arthropods. *Ecology* 37(4):843–44.
2. HOWDEN, H. F. 1957. Investigations on sterility and deformities of *Onthophagus* (Coleoptera, Scarabaeidae) induced by gamma radiation. *Annu. Entomol. Soc. Amer.* 50(1):1–9.

*3. HOWDEN, H. F., and S. I. AUERBACH. 1958. Some effects of gamma radiation on *Trogoderma sternale* Jayne. *Annu. Entomol. Soc. Amer.* 51(1):48–51.

*4. LACKEY, J. B. 1958. The suspended microbiota of the Clinch River and adjacent waters, in relation to radioactivity in the summer of 1956. ORNL-2410. 35 pp.

*5. MORGAN, K. Z., and S. I. AUERBACH. 1957. Need for reserving Melton Valley for long range ecological studies. ORNL-CF-57-12-25. 9 pp.

*6. AUERBACH, S. I. 1958. The soil ecosystem and radioactive waste disposal to the ground. *Ecology* 39(3):522–29.

7. WILLIAMS, L. G., and H. D. SWANSON. 1958. Concentration of cesium-137 by algae. *Science* 127(3291):187–88.

8. AUERBACH, S. I., D. A. CROSSLEY, JR., and M. D. ENGELMAN. 1957. Effects of gamma radiation on collembola population growth. *Science* 126(3274):614.

*9. AUERBACH, S. I., and D. A. CROSSLEY, JR. 1958. Strontium-90 and cesium-137 uptake by vegetation under natural conditions, pp. 494–499 in *Proc. 2nd Int. Conf. Peaceful Uses At. Energy*, vol. 18, Geneva. Pergamon Press, London.

*10. DAVIS, R. J., V. L. SHELDON, and S. I. AUERBACH. 1956. Lethal effects of gamma radiation upon segments of a natural microbial population. *J. Bacteriol.* 72(4):505–10.

*11. GRAHAM, E. R. 1958. Uptake of waste Sr-90 and Cs-137 by soil and vegetation. *Soil Sci.* 86(2):91–97.

*12. HOWELL, J. C. 1958. Long-range ecological study of the Oak Ridge area: I. observations on the summer birds in Melton Valley. ORNL-CF-58-6-14. 35 pp.

13. WILLIAMS, L. G. 1960. Uptake of cesium-137 by cells and detritus of *Euglena* and *Chlorella*. *Limnol. Oceanogr.* 5(3):301–11.

14. AUERBACH, S. I., and D. A. CROSSLEY, JR. 1960. A sampling device for soil microarthropods. *Acarologia* 2(3):280–87.

15. CROSSLEY, D. A., JR., and K. K. BOHNSACK. 1960. Long-term ecological study in the Oak Ridge area: III. the oribatid mite fauna in pine litter. *Ecology* 41(4):785–90.

*16. ROHDE, C. J. 1959. Studies on the biologies of two mite species, predator and prey, including some effects of gamma radiation on selected developmental stages. *Ecology* 40(4):572–79.

*17. AUERBACH, S. I., et al. 1957. Ecological research. In *Health Phys. Div. Annu. Progr. Rep. July 31, 1957.* ORNL-2384:10–39.

18. AUERBACH, S. I., et al. 1958. Ecological research. In *Health Phys. Div. Annu. Progr. Rep. July 31, 1958.* ORNL-2590:27–52.

*19. LEE, P. K., and S. I. AUERBACH. 1960. Determination and evaluation of the radiation field above White Oak Lake bed. ORNL-2755. 64 pp.
20. AUERBACH, S. I., et al. 1959. Ecological research. In *Health Phys. Div. Ann. Progr. Rep. July 31, 1959.* ORNL-2806:18–54.
*21. HOWELL, J. C., and P. B. DUNAWAY. 1959. Long-term ecological study of the Oak Ridge area: II. Observations on the mammals with special reference to Melton Valley. ORNL-CF-59-10-126. 24 pp.
22. CROSSLEY, D. A., JR., and M. E. PRYOR. 1960. The uptake and elimination of cesium-137 by a grasshopper – *Romalea microptera. Health Phys.* 4:16–20.
*23. PLUMMER, G. L. 1960. Biometric analysis of a growth response of two plant species in a radioactive waste area. ORNL-2903. 10 pp.
24. COTTRELL, W. D. 1960. Radioactivity in silt of the Clinch and Tennessee Rivers. ORNL-2847. 47 pp.
25. SCHURR, J. M., and W. N. STAMPER. 1962. A model for the accumulation of strontium and calcium by recently molted crayfish (*Cambarus longulus longerostris* Ort.). *Limnol. Oceanogr.* 7(4):474–77.
*26. OLSON, J. S., et al. 1960. Distribution of radioactive isotopes in plants, insects and soils. *Nucl. Saf.* 1(3):2–9.
27. CROSSLEY, D. A., JR., and H. F. HOWDEN. 1961. Insect vegetation relationships in an area contaminated by radioactive wastes. *Ecology* 42(2):302–17.
28. WILLARD, W. K. 1960. Avian uptake of fission products from an area contaminated by low-level atomic wastes. *Science* 132(3240):148–50.
*29. SEALANDER, J. A., JR. 1960. Subproject 4.010. The effects of sociopsychological and radiation stress on the serum proteins of the white-footed mouse (*Peromyscus leucopus*).
30. CROSSLEY, D. A., JR., and J. H. SCHNELL. 1961. Comparative elimination of radiocesium and radiostrontium by grasshoppers. *Ann. Entomol. Soc. Amer.* 54(2):459–61.
*31. OLSON, J. S., et al. 1960. Forest studies. In *Health Phys. Div. Ann. Progr. Rep. July 31, 1960.* ORNL-2994:167–85.
32. CHILDS, H. E., JR. 1960. Subproject 4.011. The effects of chronic irradiation in nature on wild small mammals in the AEC controlled area at Oak Ridge, Tennessee.
33. DUNAWAY, P. B., and S. V. KAYE. 1961. Effects of industrial oil disposal on wild mammals. *J. Mammal.* 42(4):554–56.
*34. NELSON, D. J. 1960. Biological concentration of radioisotopes from aquatic environments. *Nucl. Saf.* 2(1):81–83.
35. HOWELL, J. C. 1960. The birds of a valley. *Audubon Mag.* 62:283–88.
*36. ATYEO, W. T., E. W. BAKER, and D. A. CROSSLEY, JR. 1961. The genus *Raphignathus* Dugès (Acarina, Raphignathidae) in the United States with notes on the Old World species. *Acarologia* 3(1):14–17.
37. DUNAWAY, P. B., and S. V. KAYE. 1961. Studies of small-mammal populations on the radioactive White Oak Lake bed, pp. 167–85 in *Trans. 26th North Amer. Wildlife Nat. Res. Conf.*, March 6–8, Wildlife Management Institute.
*38. SHANKS, R. E., and J. S. OLSON. 1961. First-year breakdown of leaf litter in southern Appalachian forests. *Science* 134(3473):194–95.
39. HOWDEN, H. F., and D. A. CROSSLEY, JR. 1961. Insect species on vegetation of the White Oak Lake bed, Oak Ridge, Tennessee. ORNL-3094. 38 pp.
*40. KAYE, S. V., and P. B. DUNAWAY. 1962. Bioaccumulation of radioactive isotopes by herbivorous small mammals. *Health Phys.* 7:205–17.
41. CROSSLEY, D. A., JR., and M. P. HOGLUND. 1962. A litter-bag method for the study of microarthropods inhabiting leaf litters. *Ecology* 43(3):571–73.
42. DUNAWAY, P. B., and S. V. KAYE. 1961. Cotton rat mortality during severe winter. *J. Mammal.* 42(2):265–68.
*43. MORTON, R. J. (ed.). 1961. Status report no. 1 on Clinch River study. ORNL-3119. 81 pp.
*44. OLSON, J. S. 1961. Ecological sampling and meteorological calculation of fallout on forests near Oak Ridge. ORNL-3181. 57 pp.
*45. DUNAWAY, P. B., and S. V. KAYE. 1963. Effects of ionizing radiation on mammal populations on the White Oak Lake bed, pp. 333–38 in Schultz, V., and A. W. Klement (eds.). *Proc. First Natl. Symp. on Radioecology.* Reinhold Publ. Co., New York and AIBS, Washington, D.C.
46. KAYE, S. V., and P. B. DUNAWAY. 1963. Estimation of dose rate and equilibrium state from bioaccumulation of radionuclides by mammals, pp. 107–11 in Schultz, V., and A. W. Klement (eds.). *Proc. First Natl. Symp. on Radioecology.* Reinhold Publ. Co., New York and AIBS, Washington, D.C.
47. CROSSLEY, D. A., JR. 1963. Movement and accumulation of radiostrontium and radiocesium in insects, pp. 103–5 in Schultz, V., and A. W. Klement (eds.). *Proc. First Natl. Symp. on Radioecology.* Reinhold Publ. Co., New York and AIBS, Washington, D.C.
*48. KAYE, S. V. 1961. Movements of harvest mice tagged with gold-198. *J. Mammal.* 42(3):323–27.
*49. CROSSLEY, D. A., JR. 1963. Consumption of vegetation by insects, pp. 427–30 in Schultz, V., and A. W. Klement (eds.). *Proc. First Natl. Symp. on Radioecology.* Reinhold Publ. Co., New York and AIBS, Washington, D.C.
*50. OLSON, J. S. 1963. Analog computer models for movement of isotopes through ecosystems, pp. 121–25 in Schultz, V., and A. W. Klement (eds.). *Proc. First Natl. Symp. on Radioecology.* Reinhold Publ. Co., New York and AIBS, Washington, D.C.
*51. WITKAMP, M. 1961. Influence of radiation from an unshielded reactor on a natural microflora. ORNL-TM-29. 9 pp.
*52. OLSON, J. S., and D. A. CROSSLEY, JR. 1963. Tracer studies of the breakdown of forest litter, pp. 411–16 in Schultz, V., and A. W. Klement (eds.). *Proc. First Natl. Symp. on Radioecology.* Reinhold Publ. Co., New York and AIBS, Washington, D.C.

*53. WITHERSPOON, J. P., JR. 1963. Cycling of cesium-134 in white oak trees on sites of contrasting soil type and moisture. I. 1960 growing season, pp. 127–32 in Schultz, V., and A. W. Klement (eds.). *Proc. First Natl. Symp. on Radioecology.* Reinhold Publ. Co., New York and AIBS, Washington, D.C.

*54. KAYE, S. V. 1961. Laboratory life history of the eastern harvest mouse. *Amer. Midl. Natur.* 66(2):439–51.

55. NELSON, D. J. 1963. The strontium and calcium relationships in Clinch and Tennessee River mollusks, pp. 203–11 in Schultz, V., and A. W. Klement (eds.). *Proc. First Natl. Symp. on Radioecology.* Reinhold Publ. Co., New York and AIBS, Washington, D.C.

56. AUERBACH, S. I., and J. S. OLSON. 1963. Biological and environmental behavior of ruthenium and rhodium, pp. 509–19 in Schultz, V., and A. W. Klement (eds.). *Proc. First Natl. Symp. on Radioecology.* Reinhold Publ. Co., New York and AIBS, Washington, D.C.

*57. NEEL, R. B., and J. S. OLSON. 1962. Use of analog computers for simulating the movement of isotopes in ecological systems. ORNL-3172. 111 pp.

58. AUERBACH, S. I., et al. 1961. White Oak Lake bed studies. In *Health Phys. Div. Annu. Progr. Rep. July 31, 1961.* ORNL-3189:81–105.

59. NELSON, D. J., et al. 1961. Clinch River studies. In *Health Phys. Div. Annu. Progr. Rep. July 31, 1961.* ORNL-3189:129–39.

*60. AUERBACH, S. I. 1962. Summary of session, First National Symposium on Radioecology 1961, Cycling in the Terrestrial Environment, pp. 318–47 in *Radioactive Fallout from Nuclear Weapons Tests,* Proc. of a Conf. held in Germantown, Maryland, Nov. 15–17, 1961, Book 2. TID-7632. USAEC, Washington, D.C.

61. AUERBACH, S. I. 1961. Introductory statement. A United States ecological survey limited to the biological effects of radiation. In *Second Meeting, IAEA, March 1961. IV. Effect of radiation on ecological system of the biosphere due to atomic industry operation.* PL-30(II)/SR/11 and PL-30(II)/SR/19.

*62. OLSON, J. S., et al. 1961. Forest ecology. In *Health Phys. Div. Annu. Progr. Rep. July 31, 1961.* ORNL-3189:105–28.

63. NELSON, D. J., and B. G. BLAYLOCK. 1963. The preliminary investigation of salivary gland chromosomes of *Chironomus tentans* Fabr. from the Clinch River, pp. 367–72 in Schultz, V., and A. W. Klement (eds.). *Proc. First Natl. Symp. on Radioecology.* Reinhold Publ. Co., New York and AIBS, Washington, D.C.

*64. AUERBACH, S. I., et al. 1961. Ecological research. In *Health Phys. Div. Annu. Progr. Rep. July 31, 1961.* ORNL-3189:81–139.

*65. WITKAMP, M., and J. L. SHOOPMAN. 1961. Carbon and nitrogen in a pioneer ecosystem of kudzu vine at Copperhill, Tennessee. Unpublished ms., 17 pp. (see No. 181).

*66. MORTON, R. J. (ed.). 1962. Status report no. 2 on Clinch River study. ORNL-3202. 97 pp.

67. STRANDTMANN, R. W., and D. A. CROSSLEY, JR. 1962. A new species of soil-inhabiting mite, *Hypoaspis marksi* (Acarina, Laelaptidae). *J. Kan. Entomol. Soc.* 35(1):180–85.

*68. OLSON, J. S. 1963. Energy storage and the balance of producers and decomposers in ecological systems. *Ecology* 44(2):322–31.

*69. WITKAMP, M. 1963. Microbial populations of leaf litter in relation to environmental conditions and decomposition. *Ecology* 44(2):370–77.

*70. AUERBACH, S. I. 1962. Analytical requirements for environmental surveys. *Nucl. Saf.* 3(3):51–54.

*71. WITKAMP, M., and J. VAN DER DRIFT. 1961. Breakdown of forest litter in relation to environmental factors. *Plant Soil* 15(4):295–311.

*72. NELSON, D. J. 1962. Strontium, strontium-90 and calcium analyses of Clinch and Tennessee River clams. ORNL-TM-270. 22 pp.

*73. NELSON, D. J. 1962. Clams as indicators of strontium-90. *Science* 137(3523):38–39.

74. PLUMMER, G. L. 1962. Growth responses of *Helianthus annus* to internal calcium-45. *Bot. Gaz.* 123(4):272–78.

*75. WITHERSPOON, J. P., JR., S. I. AUERBACH, and J. S. OLSON. 1962. Cycling of cesium-134 in white oak trees on sites of contrasting soil type and moisture. ORNL-3328. 143 pp.

*76. DUNAWAY, P. B. 1962. Litter-size record for eastern harvest mouse. *J. Mammal.* 43(3):428–29.

77. LAMMERS, W. T. 1962. Density gradient separation of plankton and clay from river water. *Limnol. Oceanogr.* 7(2):224–29.

*78. MORTON, R. J. (ed.). 1962. Status report no. 3 on Clinch River study. ORNL-3370. 117 pp.

*79. AUERBACH, S. I., et al. 1962. Radiation ecology. In *Health Phys. Div. Annu. Progr. Rep. July 31, 1962.* ORNL-3347:47–72.

*80. OLSON, J. S. 1962. Surveys of environmental radioactivity. *Nucl. Saf.* 4(1):88–95.

*81. AUERBACH, S. I., and V. SCHULTZ. 1962. Onsite ecological research of the division of biology and medicine at the Oak Ridge National Laboratory. TID-16890.

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1	114	178	229	279	330	382	426	467
2	115	179	230	280	331	383	427	468
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8	118	181	232	283	333	385	429	470
13	119	182	233	284	334	386	430	471
14	124	184	234	285	335	387	431	472
15	126	185	235	286	336	388	432	473
20	127	186	236	287	337	389	433	474
22	128	187	237	288	340	391	434	475
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27	131	190	239	290	342	394	436	477
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